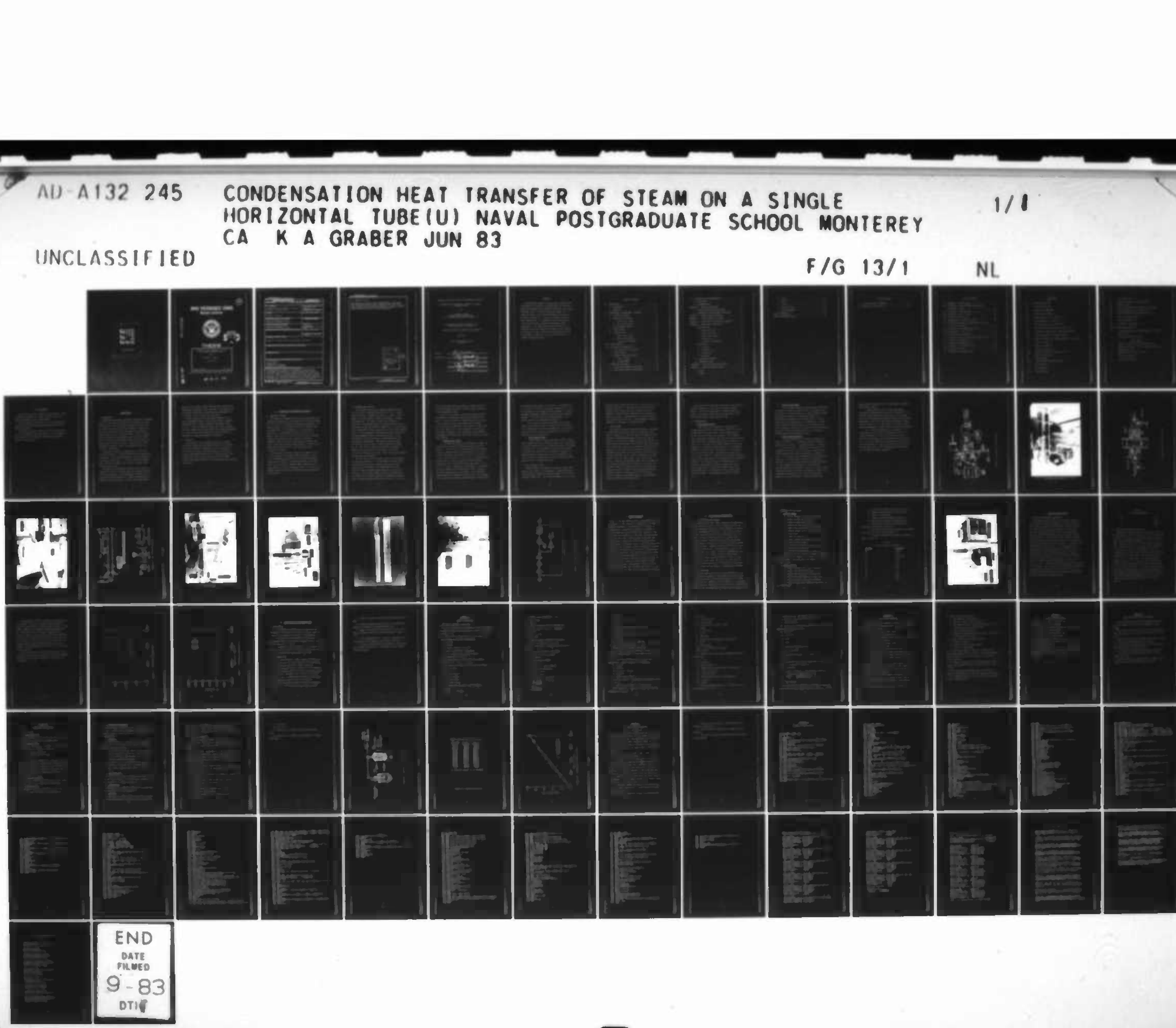
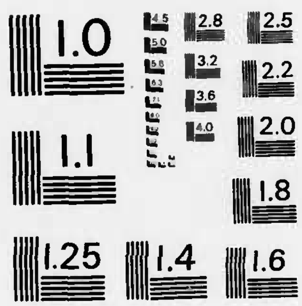
AD-A132 245 CONDENSATION HEAT TRANSFER OF STEAM ON A SINGLE HORIZONTAL TUBE(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA K A GRABER JUN 83 1/1

UNCLASSIFIED F/G 13/1 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

CONDENSATION HEAT TRANSFER OF STEAM ON A SINGLE HORIZONTAL TUBE

by

Kenneth A. Graber

June 1983

Thesis Advisor: P. J. Marto

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Condensation Heat Transfer of Steam on a Single Horizontal Tube		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis June 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Kenneth A. Graber		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE June 1983
		13. NUMBER OF PAGES 82
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Heat Transfer
Condensation
Experimental Apparatus
Enhanced Condensation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An experimental apparatus was designed, constructed and instrumented in an effort to systematically and carefully study the condensation heat-transfer coefficient on a single, horizontal tube. A smooth, thick-walled copper tube of length 133.5 mm, with an outside diameter of 15.9 mm and an inside diameter of 12.7 mm was instrumented with six wall thermocouples. The temperature rise across the test section was measured

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (cont'd)

accurately using quartz crystal thermometers. The inside heat-transfer coefficient was determined using the Sieder-Tate correlation with leading coefficient of 0.029. Initial steam side data were taken at atmospheric pressure to test the data acquisition/reduction computer programs.

Approved for public release; distribution unlimited

Condensation Heat Transfer of Steam on a Single Horizontal Tube

by

Kenneth A. Graber
Lieutenant, United States Navy
B.S., United States Naval Academy, 1977

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
June 1983

Author: K G Graber

Approved by: P.J. Marto
Thesis Advisor

Second Reader

P.J. Marto
Chairman, Department of Mechanical Engineering

Dean of Science and Engineering

ABSTRACT

An experimental apparatus was designed, constructed and instrumented in an effort to systematically and carefully study the condensation heat-transfer coefficient on a single, horizontal tube. A smooth, thick-walled copper tube of length 133.5 mm, with an outside diameter of 15.9 mm and an inside diameter of 12.7 mm was instrumented with six wall thermocouples. The temperature rise across the test section was measured accurately using quartz crystal thermometers. The inside heat-transfer coefficient was determined using the Sieder-Tate correlation with leading coefficient of 0.029. Initial steam side data were taken at atmospheric pressure to test the data acquisition/ reduction computer programs.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

A_1	Inlet fin area (m^2)
A_2	Outlet fin area (m^2)
C_i	Sieder-Tate Coefficient
C_p	Specific heat (Kj/Kg - K)
D_i	Inside diameter of test tube (m)
D_o	Outside diameter of test tube (m)
D_r	Outside diameter at outlet end (m)
h_i	Inside heat-transfer coefficient (W/m^2 - K)
h_o	Condensation heat-transfer coefficient (W/m^2-K)
k_{cu}	Thermal conductivity of copper (W/m-K)
k_f	Thermal conductivity of water evaluated at T_b (W/m-K)
L_1	Inlet fin length (m)
L_2	Outlet fin length (m)
L	Condensing length (m)
LMTD	Log mean temperature difference ($^\circ$C)
$\dot{m}$	Mass flow rate (kg/s)
Nu	Nusselt number
Nu_c	Computer generated Nusselt number
P_1	Fin parameter 1
P_2	Fin parameter 2
Pr	Prandtl number

Q	Heat flow rate (W)
Q_p	Heat flux based on outside area (W/m^2)
Re	Reynolds number
R_m	Wall resistance based on outside area (m^2-K/W)
T_1	Inlet temperature to test section (^oC)
T_2	Outlet temperature from test section (^oC)
T_b	Bulk fluid temperature (^oC)
T_s	Steam temperature (^oC)
T_w	Average wall temperature (^oC)
T_{w1}-T_{w6}	Wall temperatures (^oC)
U_o	Overall heat transfer coefficient based on outside area (W/m^2-K)
V_w	Cooling Water velocity (m/s)

Greek Symbols

μ_f	Dynamic viscoscity of water evaluated at T_b
μ_w	Dynamic viscoscity of water at average inner wall temperature (N-S/m^2)
ν_f	Specific volume of fluid (m^3/Kg)
η_1	Inlet fin efficiency
η_2	Outlet fin efficiency

ACKNOWLEDGEMENT

The author would like to take this opportunity to thank his advisor, Professor P. J. Marto for his support and guidance throughout this research effort.

Special thanks are extended to Dr. A. S. Wanniarachchi, without whose expertise and guidance this paper would not have been possible.

The author would also like to thank the lab supervisor, Mr. Tom Christian and lab technician, Mr. Ron Longuiera for their technical help during the design and construction phases of this project.

I. INTRODUCTION

A. SIGNIFICANCE

Experimental studies have shown that enhancement techniques applied on the steam side of horizontal condenser tubes may significantly reduce the thermal resistance and thus reduce the overall size and weight of the condenser. Several workshops and conferences on heat exchangers have addressed specific areas in need of research {Refs. 1,2,3}. Recently, there have been many investigations into possible alternatives for enhanced heat-transfer surfaces in the design of heat exchangers {Refs. 2,4,5,6,7}. Webb {Ref. 8} in 1980 published an excellent review of enhancement methods as applied to condensers.

Enhancement techniques can generally be divided into two major categories: water-side enhancement and steam-side enhancement. Water-side enhancement is covered extensively by Bergles & Jensen {Ref. 9}. Various steam-side enhancements include low integral fins, surface coatings, fluted tubes and roped tubes.

The goal of any enhancement technique is to lower the thermal resistance to the point where the technique becomes economically feasible. Althouth Bergles & Jensen {Ref. 9} show that extensive reduction in thermal resistance can be obtained on the water-side, it is felt that a significant portion of the overall thermal resistance can be reduced by enhancement techniques on the steam-side. Both methods must be examined independently because the best enhancement for one side may not be the best for both sides.

Several research efforts have been undertaken at the Naval Postgraduate School to model steam surface condensers and analyze their thermal performance numerically {Refs. 10,11,12}. Based on numerous computer runs used to analyze different combinations of both inside and outside enhancements, it is felt that further experimental research should be conductdd on steam-side enhancement techniques.

B. OBJECTIVE

The objective of this research effort was to obtain smooth-tube baseline data necessary to act as the standard for future enhancement techniques. Both the inside and outside heat-transfer coefficients had to be identified and all experimental methods used to obtain and reduce the recorded data had to be well documented so that future testing using enhanced tubes would be performed under identical conditions.

II. DESCRIPTION OF EXPERIMENTAL APPARATUS

A. OVERVIEW OF SYSTEM

The experimental apparatus used in this investigation, as described in Reference 13, was constructed of stainless steel and 152.4 mm (6 in) diameter Corning Pyrex glass piping. An overall schematic of the system is shown in Figure 2.1 and a photograph is shown in Figure 2.2. A boiler section 304.8 mm (12 in) in diameter and 487.7 mm (19.2 in) in height, with a 304.8 mm (12 in) to 152.4 mm (6 in) reducing section, provides steam for the system. Ten Watlow 4000-Watt, 480-Volt stainless steel immersion heaters are used to provide input power. Each heater is 15.9 mm (5/8 in) diameter and 279.4 mm (11 in) long. All heaters are connected in parallel.

Stean travels up the glass piping to a height of 3.1 m (10 ft) and makes a 180-degree bend followed by a 1.52 m (5 ft) straightening section prior to passing through the condenser test section. Two helically-wound, water cooled coils of 9.5 mm (3/8 in) diameter copper tubing act as a dump condenser to remove all excess steam. A 25.4 mm (1 in) diameter stainless steel tube returns condensate by gravity to the boiler.

B. CONDENSER TEST SECTION

The condenser test section is made of stainless steel, 152.4 mm (6 in) in diameter and 457.2 mm (18 in) in length. Figure 2.3 shows a schematic and Figure 2.4 shows a photograph of the test section. Steam is condensed on a single horizontal tube. Two types of smooth test tubes were constructed of high-grade copper to provide baseline data for inside and outside heat-transfer coefficients. An instrumented tube, constructed as shown in Figure 2.5, and an uninstrumented tube of the same dimensions were used to obtain initial data. The uninstrumented tube was constructed identical to the instrumented tube but there were no channels machined for thermocouple installation. The active condensing length was 133.3 mm (5.25 in) with a suitable correction applied for the "fin" effect created by both ends of the tube not being in direct contact with the steam on the outside, but cooled by water on the inside. The fin-effect calculations are described in Appendix A.

The test tube is held in place by nylon holding rings as described in Reference 13. An additional O-ring was placed inside the inlet section to prevent cooling water from leaking into the grooves of the instrumented test tube. Nylon was used to minimize axial conduction from the test section. A nylon mixing chamber described in Reference 13 was placed in the outlet side prior to measuring the temperature to ensure thorough mixing of the coolant. A 114.3 mm

(4.5 in) diameter double glass window, heated by hot air to prevent fogging, was used to provide visual observation of the condensing process.

A 12.7 mm (0.5 in) port at the dump condenser section was used as an overpressure relief line and boiler fill line. An in-line 0.108 MPa (1 psig) relief valve was used to allow gases to escape while warming up the system. A 12.7 mm (0.5 in) vacuum valve was placed in a branch line off of the relief line to allow filling of the boiler as described in Appendix B. All connections were assembled with Swagelok fittings sealed with Teflon ferrules to ensure leak tighness.

1. Cooling Water System

A closed loop cooling water system was designed and constructed to circulate cooling water through the test section. A 0.001 cu-m (2.8 cuft) stainless-steel tank was used as a reservoir which fed the suction end of a close coupled centrifugal pump rated at 0.0022 m^3/s (11 GPM) at 12.19 m (40 ft) of head. A 19.1 mm (3/4 in) diameter bronze needle valve was used to regulate the flow which was monitored by a rotameter with a full-scale range of 6.94 E-4 m^3/s (11GPM). See Figure 2.6 for details. The maximum flow rate through the test tube was 4.57 m/s (15 fps) at an inlet temperature of 15.6°C (60°F). The centrifugal pump needle valve arrangement provided a flow rate accuracy of 0.5 percent on a scale with 100 divisions. After leaving the condenser test section, the water was cooled back down to the 15.6°C (60°F) bath temperature by means of a 11.73 kW (40,000-BTU/Hr) direct expansion heat exchanger. The heat-exchanger refrigerant dissipates the heat to the atmosphere through a 10.55 kW (3 ton) air-conditioning unit. The chiller section is illustrated in Figure 2.7.

The closed loop cooling water system was chosen in order to more closely monitor the water flow rate and the inlet temperature to the test condenser tube. The reservoir is easily filled by use of the installed fill line and drained by use of a siphon tube.

2. Test Condenser Tubes

Initial smooth tube data were taken using an instrumented copper tube as illustrated in Figure 2.8. Construction of the instrumented tube was carefully performed in accordance with Figure 2.5. The instrumented tube must be installed according to the instructions as outlined in Appendix D to prevent damage to thermocouple wires and leakage from the system. Each wall thermocouple should be checked for proper operation prior to taking any data.

C. DUMP CONDENSER SYSTEM

A dump condenser is installed to condense excess steam from the test section. Cooling water is supplied from tap water through two parallel, helically-wound, 9.5 mm (3/8 in) diameter, copper coils. One smaller diameter coil is placed inside the other, while both are 457.2 mm (18 in) high. The tap water flow rate is controlled by a 19.05 mm (3/4 in) diameter bronze needle valve and is monitored using a rotameter. System internal pressure can be controlled by reducing the flow of cooling water to the dump condenser. For a given boiler power input, a dump condenser rotameter reading will correspond to a system pressure.

D. VACUUM SYSTEM

Two operational vacuum systems are available to maintain sub-atmospheric conditions within the apparatus; an air ejector, powered by 1.1 MPa (160 psig) air supplied by the Mechanical Engineering Department reciprocating air compressure, and a portable mechanical vacuum pump (Figure 2.6). Either system may be used to initially draw down the pressure but only the air ejector may be used while the system in in operation due to the lack of a nitrogen cold trap on the mechanical vacuum pump. The vacuum system inlet valve can be used to throttle the air ejector to maintain any system pressure above 13.8 kPa (2 psia). This system is also useful in removing noncondensable gases from the apparatus. The sequential drawing down of vacuum on the system while steaming, shutting the vacuum inlet valve and raising the pressure to about 13.8 kPa (2 psia) by adjusting the dump condenser throttle valve was found to be an effective method of removing noncondensable gases. This procedure should be repeated about three times.

The system will not maintain vacuum due to cracked silver soldered connections at the base of the dump condenser section. The copper tubing used as a dump condenser penetrates the stainless steel base and was sealed with silver solder which cracked, producing small leaks.

E. INSTRUMENTATION

1. Heater Power Control

Power input to the apparatus is regulated by a voltage sensing circuit. Line voltage (440-VAC) is fed into a differential input precession voltage attenuator which divides the line voltage by one-hundred. This stepped-down voltage passes through a True Root Mean Square converter stage on which the integrated period has been reduced to about 1 ms. The output of the TRMS converter is buffed and compared to a reference voltage provided by a potentiometer mounted on the front panel. See Figure 2.9 for a general view of the control panel. The comparator output is fed to the control input of a Halmar silicon-controlled rectifier power supply which provides the voltage applied to the heater elements. The buffered output of the TRMS converter is amplified and filtered to provide a normalized voltage output proportional to the actual voltage output of the power supply which is monitored by the data acquisition/reduction system. A line diagram is provided in Figure 2.10.

2. Pressure Measurement

A U-Tube mercury manometer, calibrated in millimeters, is installed to measure system pressure. The pressure tap is located at the test section and is tilted upward to avoid steam from collecting in the manometer (Figure 2.4). A vacuum valve is installed in the pressure line to prevent condensation from accumulating in the manometer. A small amount of water eventually collects in the manometer, but this discrepancy is taken into account by the data acquisition/ reduction software with manual input to the keyboard of mercury height followed by water height.

3. Temperature Measurement

Various temperatures are monitored throughout the system to include: 1. test section cooling water inlet and outlet, 2. steam, 3. condensate return, 4. ambient, 5. test tube wall and 6. cooling water reservoir. The temperature rise across the test section is measured by a Hewlett-Packard quartz crystal thermometer accurate to $0.04^{\circ}C$. The location of the temperature probes are shown in Figure 2.4. The cooling water reservoir temperature is monitored by a direct readout alcohol-in-glass thermometer. All other temperature measurement is accomplished by copper-constantan thermocouples: two for the steam, six for the test tube wall and one for the condensate return. Each temperature measurement, except for the cooling water reservoir, is read directly by a Hewlett-Packard 3497A data acquisition system, which is controlled by a Hewlett-Packard 9826 computer.

During operation, the six wall thermocouples experienced temperature fluctuations on the order of $\pm$ 10 μV. Therefore, each thermocouple was scanned for ten seconds and the ten readings were averaged to obtain a more accurate measurement. All other thermocouples maintained a steady readout with only 1.0 μV fluctuation. The quartz crystal thermometerappeared to operate very well with no fluctuations.

Two of the thermocouples were calibrated. One thermocouple was made from the beginning of a spool of copper-constantan wire and one was made from the end. All other thermocouples were fabricated from wire on this spool. It was assumed that the properties of the copper and constantan do not change along a given section of wire for any given spool. Both thermocouples were calibrated by the method described in Appendix E.

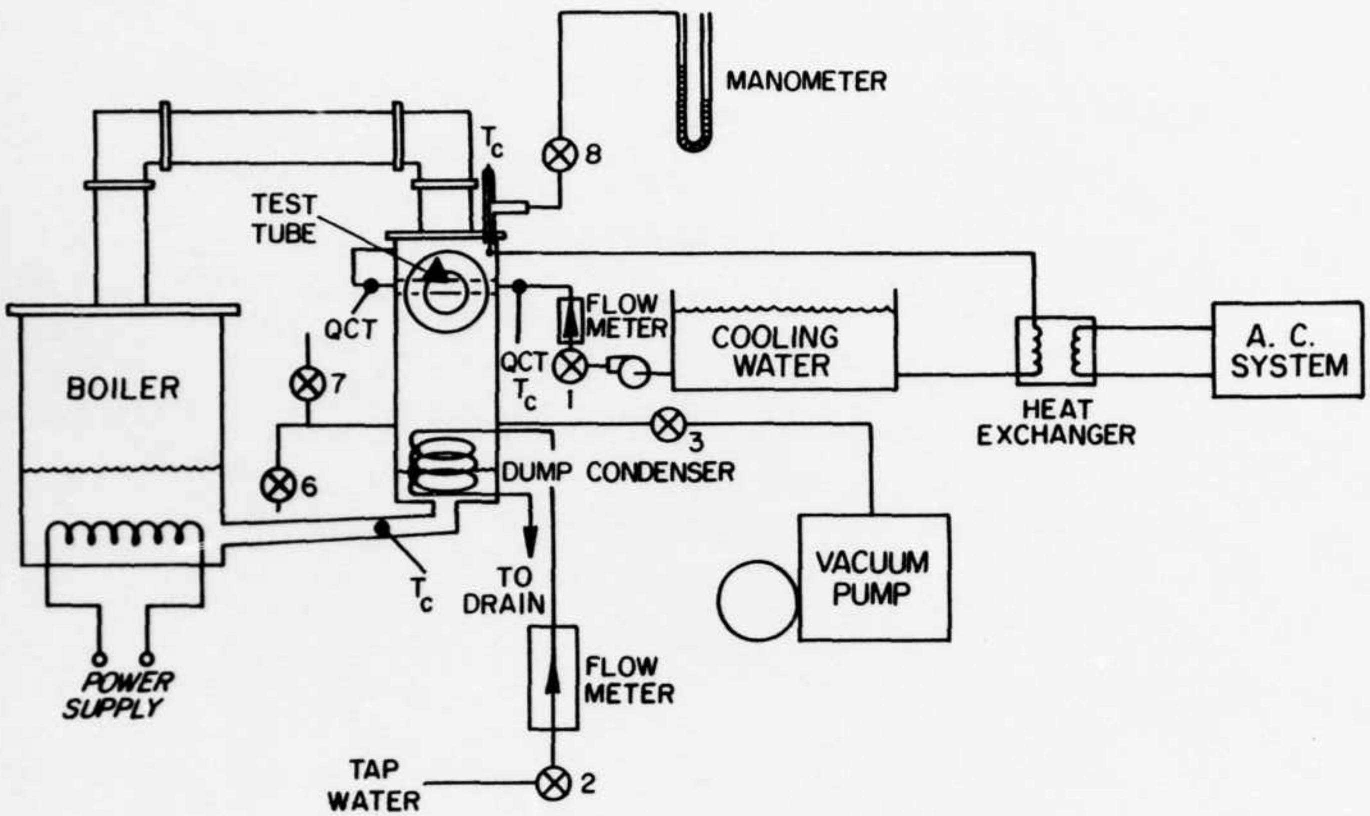


Figure 2.1 Schematic of Test Apparatus

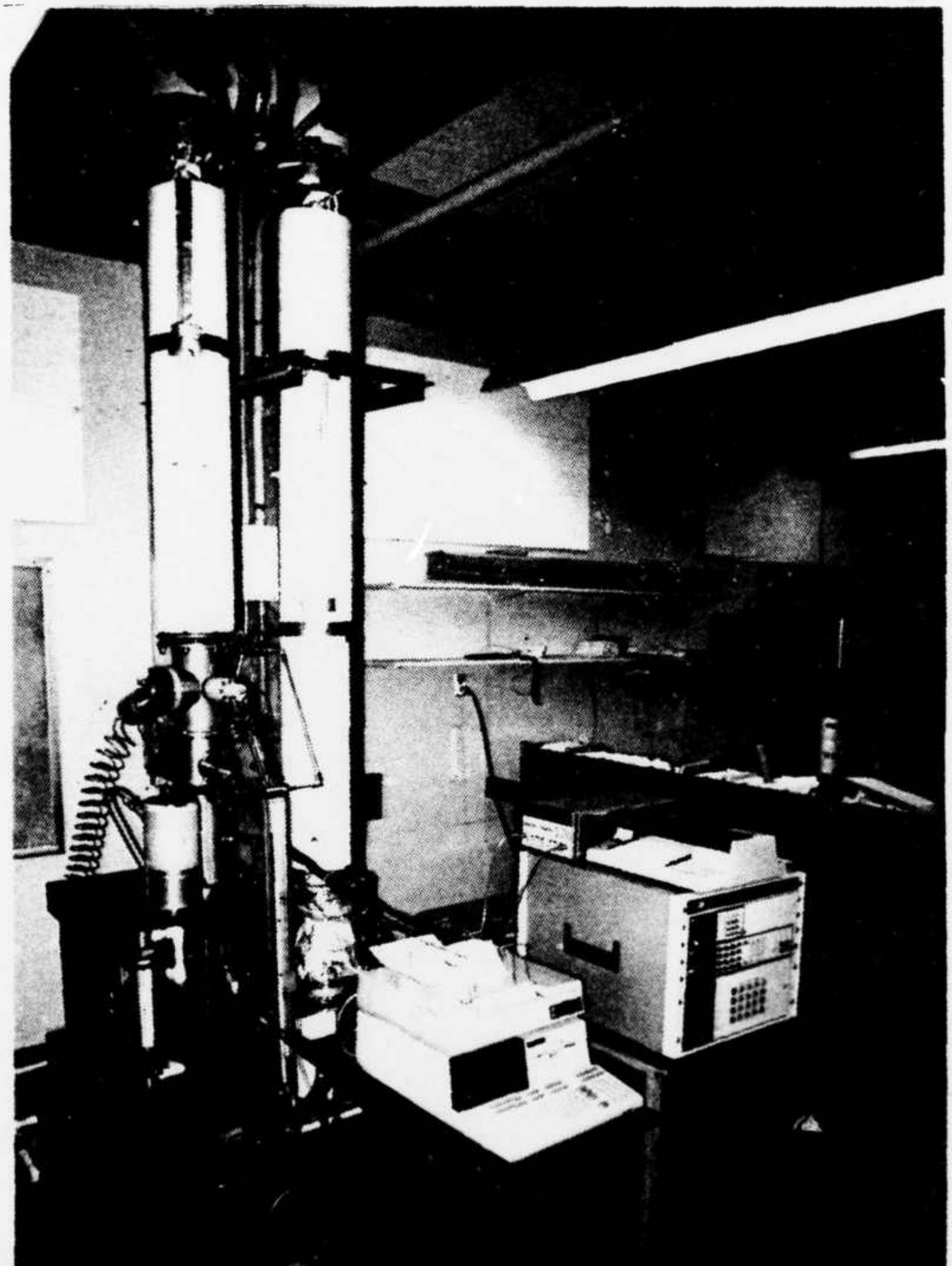


Figure 2.2 Photograph of Overall System Showing Data Acquisition System

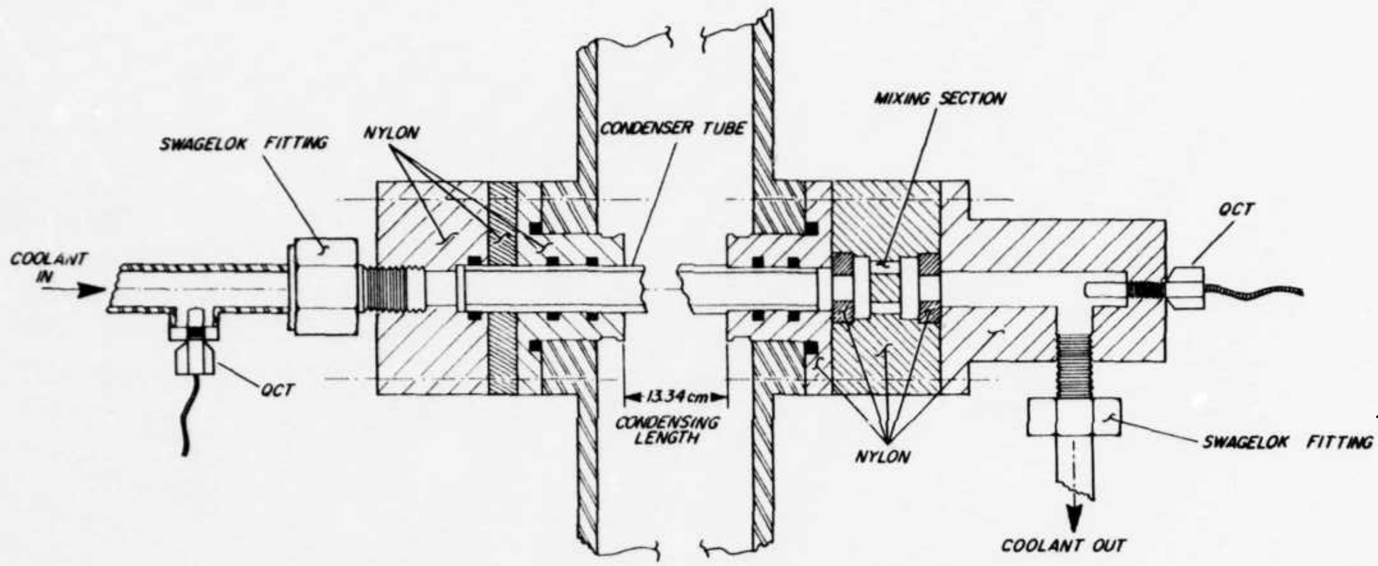


Figure 2.3 Schematic of Test Section

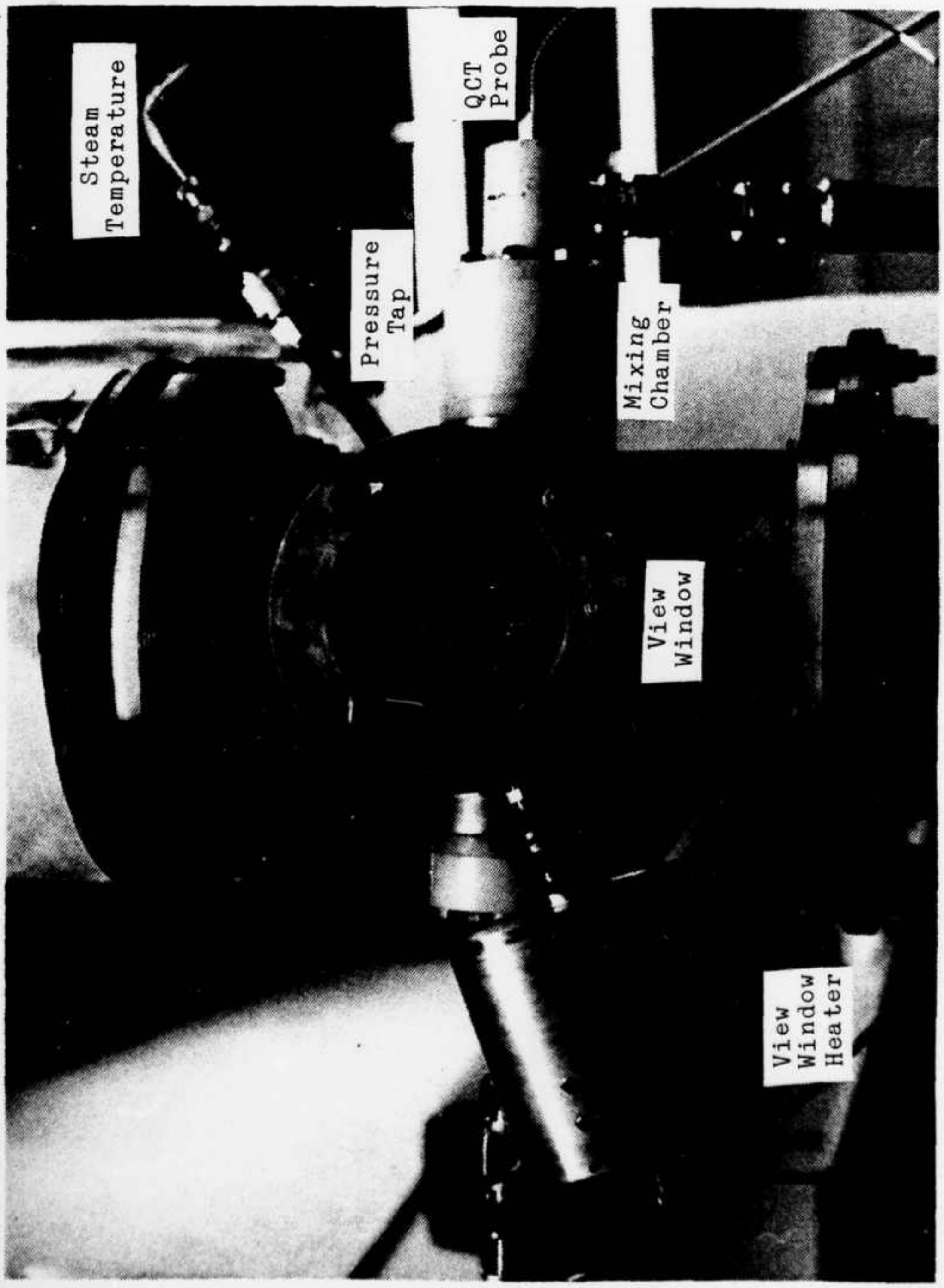


Figure 2.4 Photograph of Test Section

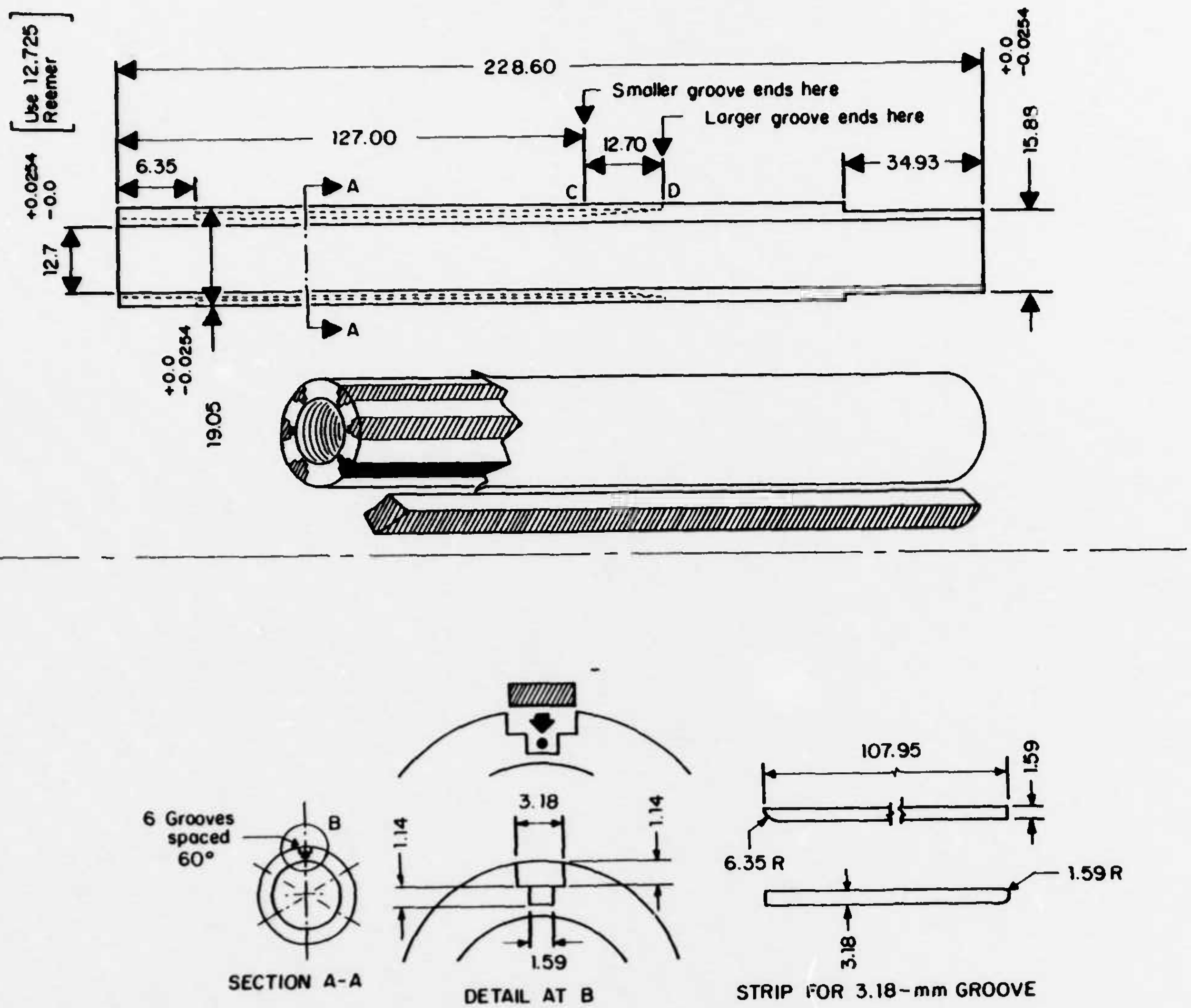


Figure 2.5 Test Tube Construction

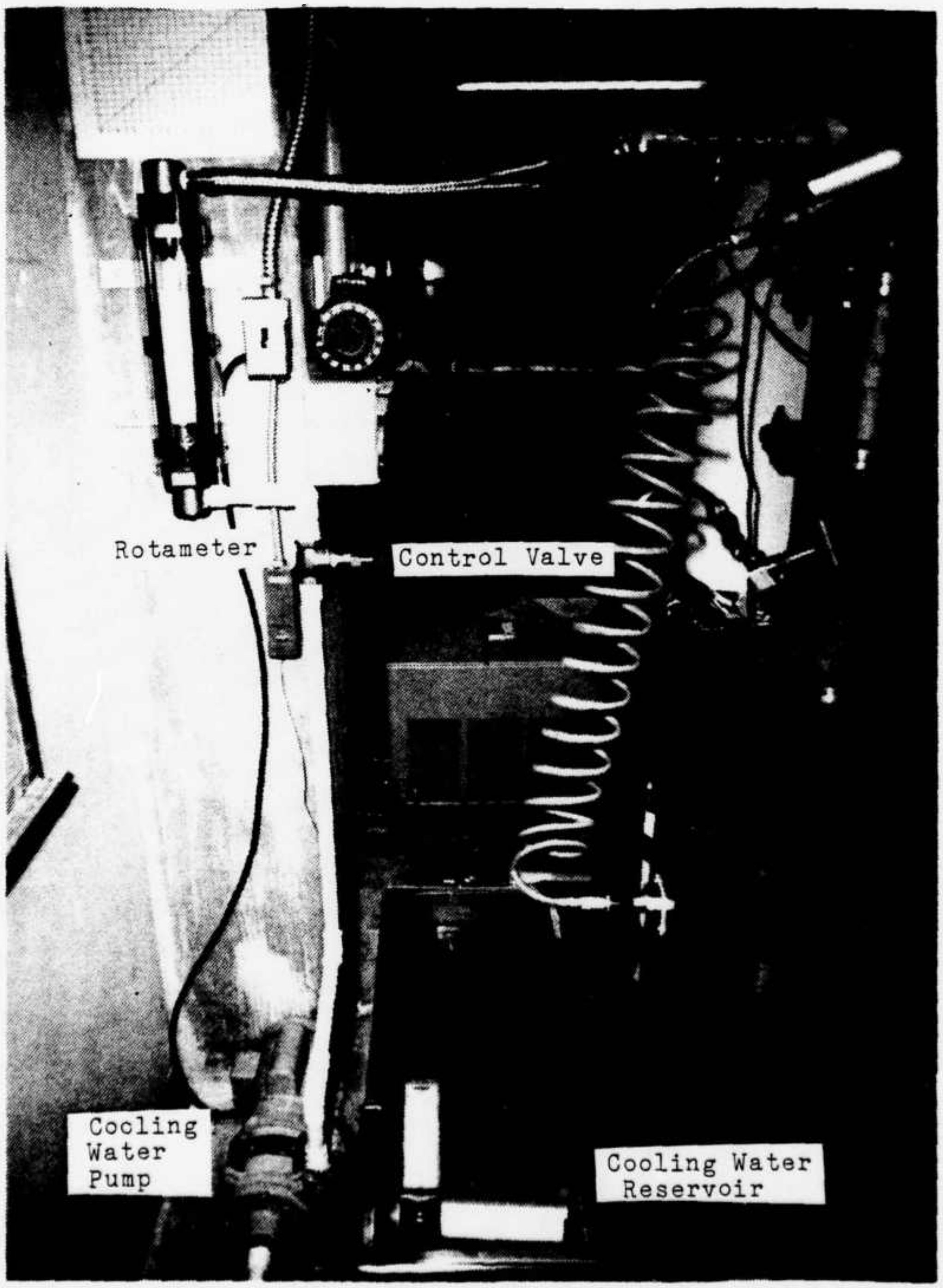


Figure 2.6 Photograph of Cooling Water System

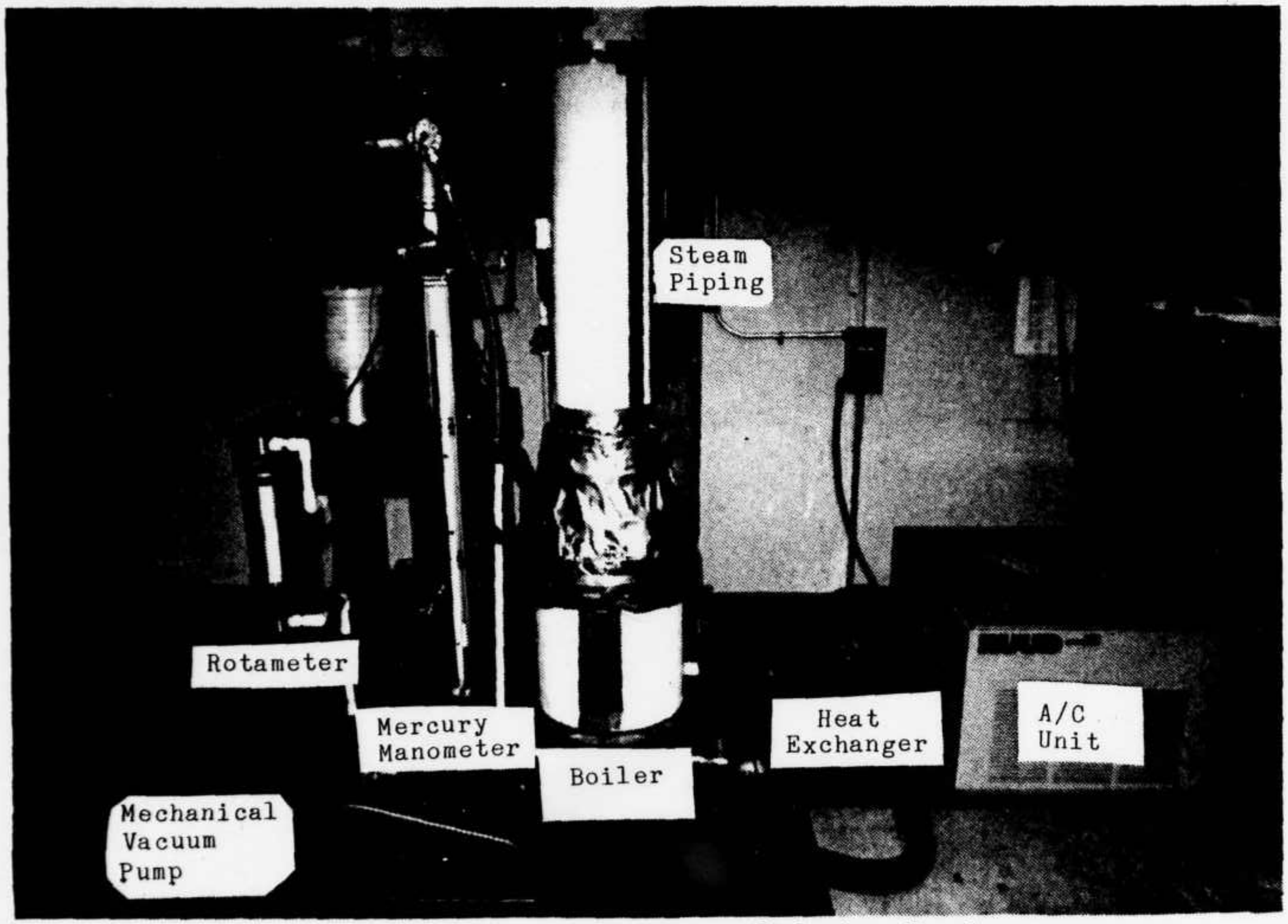


Figure 2.7 Photograph of Overall System Showing Boiler and Air Conditioning Unit

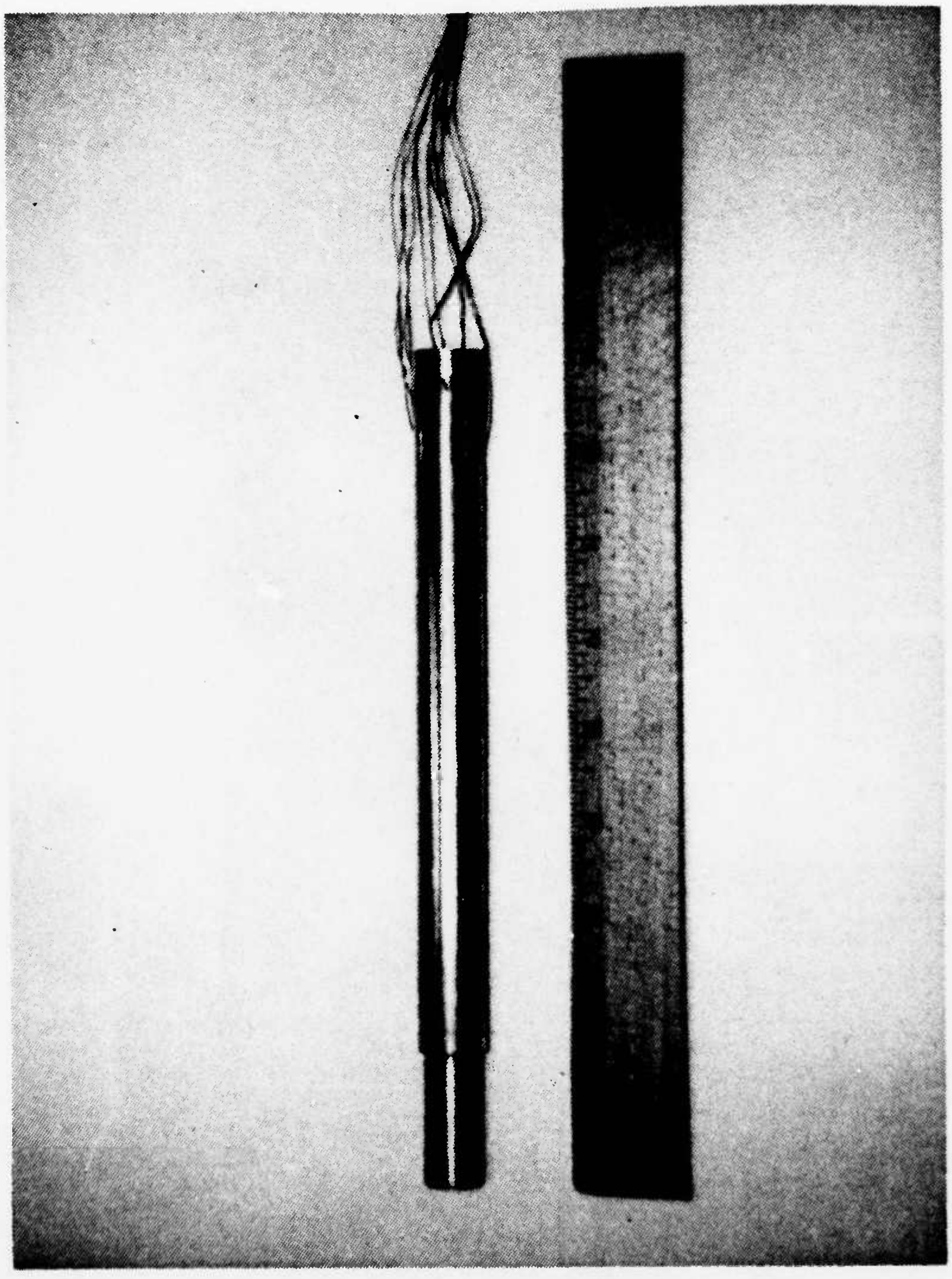


Figure 2.8 Photograph of Instrumented Test Tube

Figure 2.9 Photograph of Control Panel

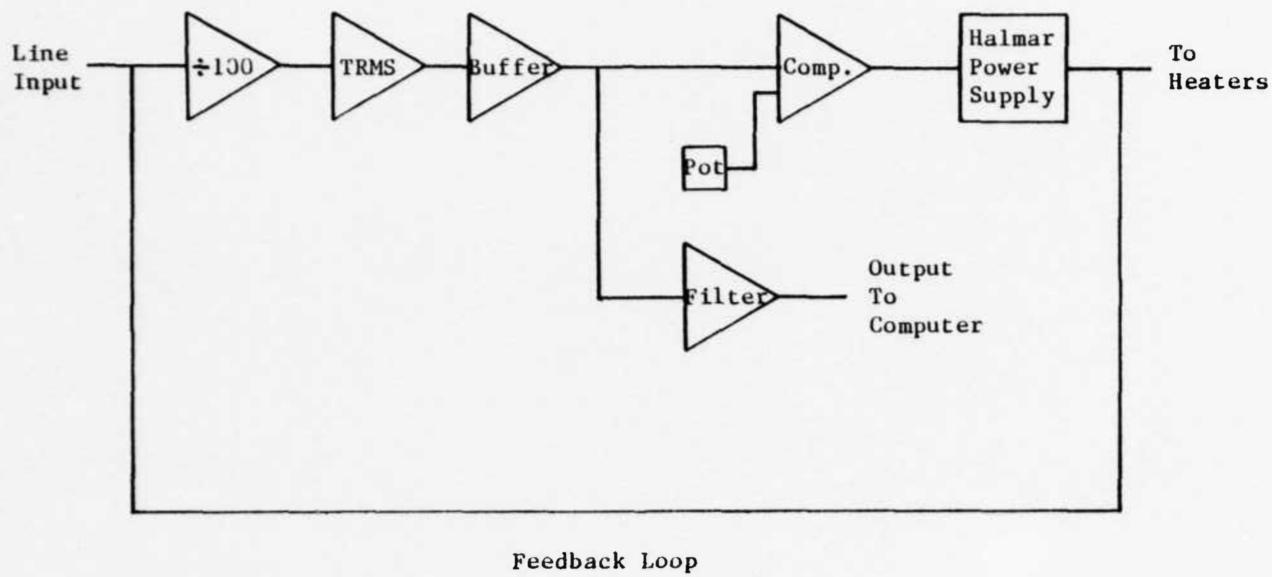


Figure 2.10 Power Controller Circuitry

III. SYSTEM OPERATION

After a thorough cleaning using the procedures described in Appendix F, a test tube may be installed by the steps outlined in Appendix D. Each system start-up should be accomplished by the procedures described in Appendix B. Once the system has reached steady-state conditions (about 30 minutes), data taking for a given test tube may commence. During each data run, a frequent check of the test tube should be made to ensure the desired condensation mode: either dropwise or filmwise. When the tube cleaning procedures of Appendix F are utilized, filmwise condensation conditions will last for about four hours, followed by mixed filmwise and dropwise conditions. Each data set consisted of eight cooling water velocities ranging from 1.37 m/s to 3.84 m/s through the test section. At a given velocity setting, the flow was allowed to steady out for two minutes before recording temperatures. The computer signalled by both audio and visual means when the system was ready for a new data point. An entire data set was recorded in 40 minutes.

IV. DATA ACQUISITION/REDUCTION

A. DATA ACQUISITION AND STORAGE

A Hewlett-Packard (HP) 3054A automatic data acquisition/control system was used to monitor temperatures from the thermocouples and the quartz crystal thermometers. Figure 4.1 shows a photograph of the system. This system included an HP 3497A data acquisition/control scanner and an HP 3456A digital voltmeter with a resolution of 100-nanovolts. An HP 9826A computer, interfaced with the data acquisition/control system, was used as a controlling unit and provided storage for data. Information was entered through the keyboard to prompt the data acquisition/control unit to automatically scan each channel. Channel assignments are listed in Table 1. These raw data were then transferred to a computer disk under a user-specified file name for later reduction to usable form. The ability to store raw data directly enabled these data to be reduced at any time and allowed flexibility for changes to data-reduction software.

B. DATA REDUCTION

Following data acquisition for each data point, results were computed according to the stepwise procedure outlined in the next section, and were then printed on an HP 6771G thermal printer. Appendix G shows an example of a representative data run. Results were also stored in a user-specified plot data file for subsequent plotting using the program PLOT.

C. STEPWISE SOLUTION PROCEDURE

1. Program SIEDER

a. Compute average cooling water temperature.

b. Compute average wall temperature.

c. Compute cooling water velocity.

d. Compute mass flow rate of cooling water.

e. Compute heat transferred to cooling water.

f. Compute average inside wall temperature.

g. Compute LMTD.

h. Assume fin efficiency.

i. Compute inside heat-transfer coefficient.

j. Compute Nusselt number.

k. Calculate fin efficiency using previously-calculated, heat-transfer coefficient.

l. Recalculate heat-transfer coefficient.

Recalculate Nusselt number and compare to Nusselt number found in j and iterate if not within 1%. Figure 5.1 shows an example of plotted data and Appendix G shows a listing of PLOT.

2. Program NSFDRP

a. Compute average cooling water temperature.

b. Compute cooling water velocity.

c. Compute mass flow rate of cooling water.

d. Compute heat transferred to cooling water.

e. Compute log mean temperature difference.

f. Compute overall heat-transfer coefficient based on outside area.

g. Compute wall resistance based on outside area.

h. Compute Reynolds number of cooling water.

i. Assume fin efficiency.

j. Compute inside heat-transfer coefficient.

k. Calculate cooling water temperature rise.

l. Calculate fin efficiency using previously-calculated, heat-transfer coefficient.

m. Recalculate heat-transfer coefficient and iterate if not within 1% of the value found in h.

n. Calculate condensing heat-transfer coefficient from U_0, R_w and h_i.

TABLE I

HP 3497A Channel Assignments

Channel	Assignment
20	steam
21	steam
22	condensate
23	room
24	room
25	wall
26	wall
27	wall
28	wall
29	wall
30	wall

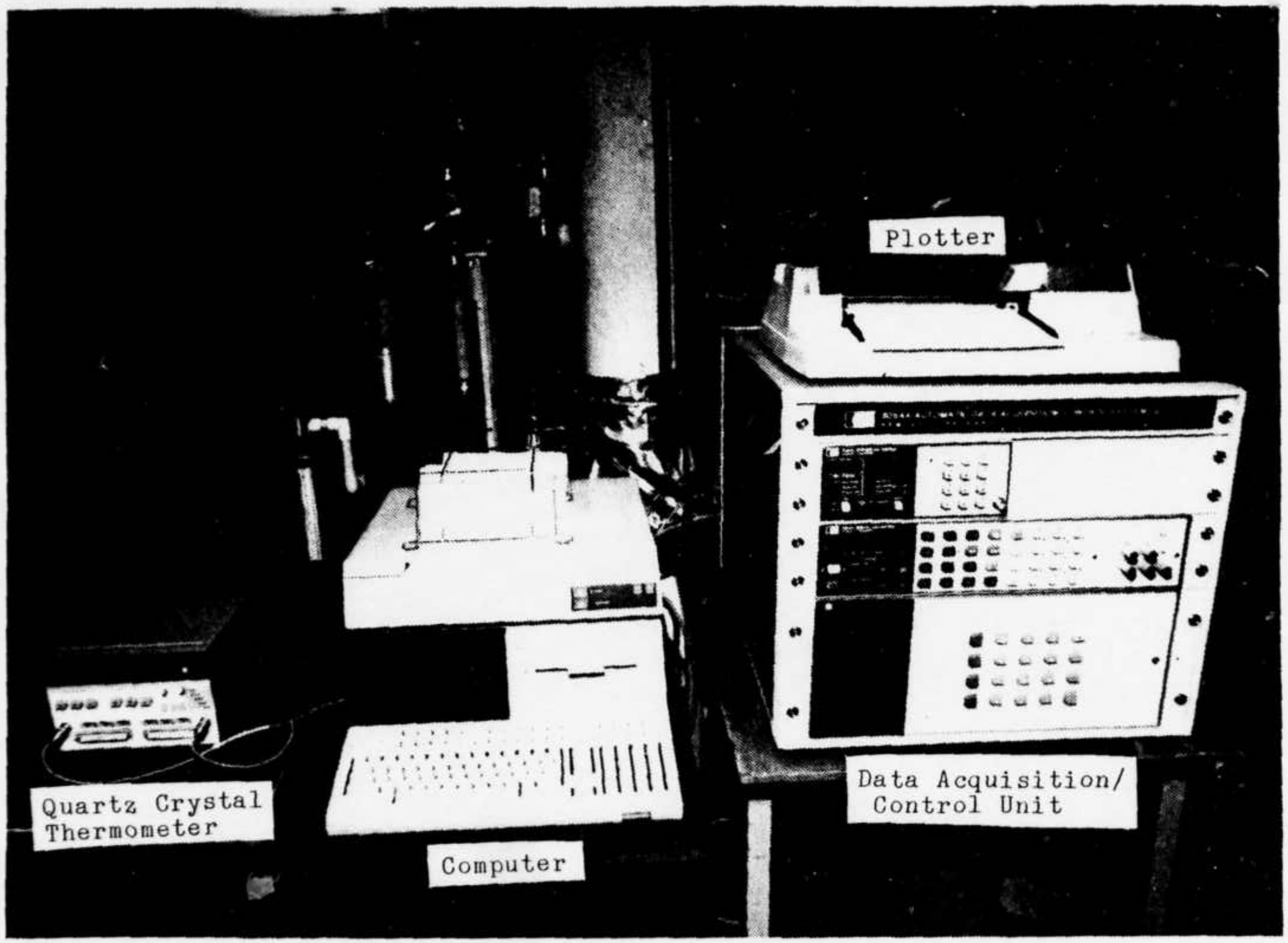


Figure 4.1 Photograph of Data Acquisition/Reduction System

V. RESULTS AND DISCUSSIONS

A. INSIDE HEAT-TRANSFER COEFFICIENT

Experimental data were taken at atmospheric pressure by the procedures outlined in Chapter III. Twelve data sets were taken to determine the inside heat-transfer coefficient. The first four data sets were utilized to test the data acquisition/reduction program SIEDER and the middle five data sets experienced mixed filwise and dropwise condensation conditions. Data sets 10-12 showed filmwise condensation throughout each of the data collection sets. Figure 5.1 is a plot of data taken during run number 10. Similar results were obtained for data runs 11-12. The analysis of all data showed a Sieder-Tate coefficient of 0.029 ± 0.001 to be representative for the experimental apparatus (Table II). The Sieder-Tate correlation for fully developed turbulent flow has a leading coefficient of 0.027 {Ref. 16}. Rose {Ref. 14} shows a leading coefficient of 0.030 with an L/D ratio of 17, which is in good agreement with the results of this thesis. The L/D ratio for the experimental apparatus used during this thesis was 18, well below that for fully developed flow {Ref. 16}; therefore the inside heat-transfer coefficient was correspondingly higher.

TABLE II

Sieder-Tate Coefficients

File	Ci
10	.0291
11	.0287
12	.0287

B. OUTSIDE HEAT-TRANSFER COEFFICIENT

Experimental data were taken at atmospheric pressure by the procedures outlined in Chapter III. Four data sets were recorded to detemine the outside heat-transfer coefficient using the program NSFDRP (Appendix G) to reduce the raw data. Figure 5.2 shows a plot of the four data sets along with a curve showing the corresponding Nusselt prediction. All of the data lie above the theoretical curve. This discrepancy has two possible explanations. Either dropwise condensation and/or vapor shear associated with a vapor velocity of 3 m/s could increase the condensation heat transfer coefficient. The effect of vapor shear has been studied by many investigators including Rose as described in a very recent report {Ref. 18}. Rose reported that when vapor velocity was increased to 7 m/s for refrigerant-113, the condensing coefficient increased by 20%. The presence of dropwise condensation significantly raises the heat-transfer coefficient, sometimes as much as ten times {Ref. 17}.

A large amount of scatter occurred in the recorded data. This situation could have occurred due to noncondensable gases and the inability to regulate system pressure. During normal operation, the Mechanical Engineering Department air compressor (160 psi) was used to operate the air ejector. During the condensation heat transfer coefficient runs, this air compressor was inoperative; therefore, house air (50 psi) was used. This source of air had a very low capacity and fluctuated greatly during each data run, perhaps causing varying amounts of air to be in the vicinity of the test tube.

Due to limited and lack of reliable data, very little can be concluded for the results thus far for the condensing coefficient. More data is necessary to reach any final conclusions.

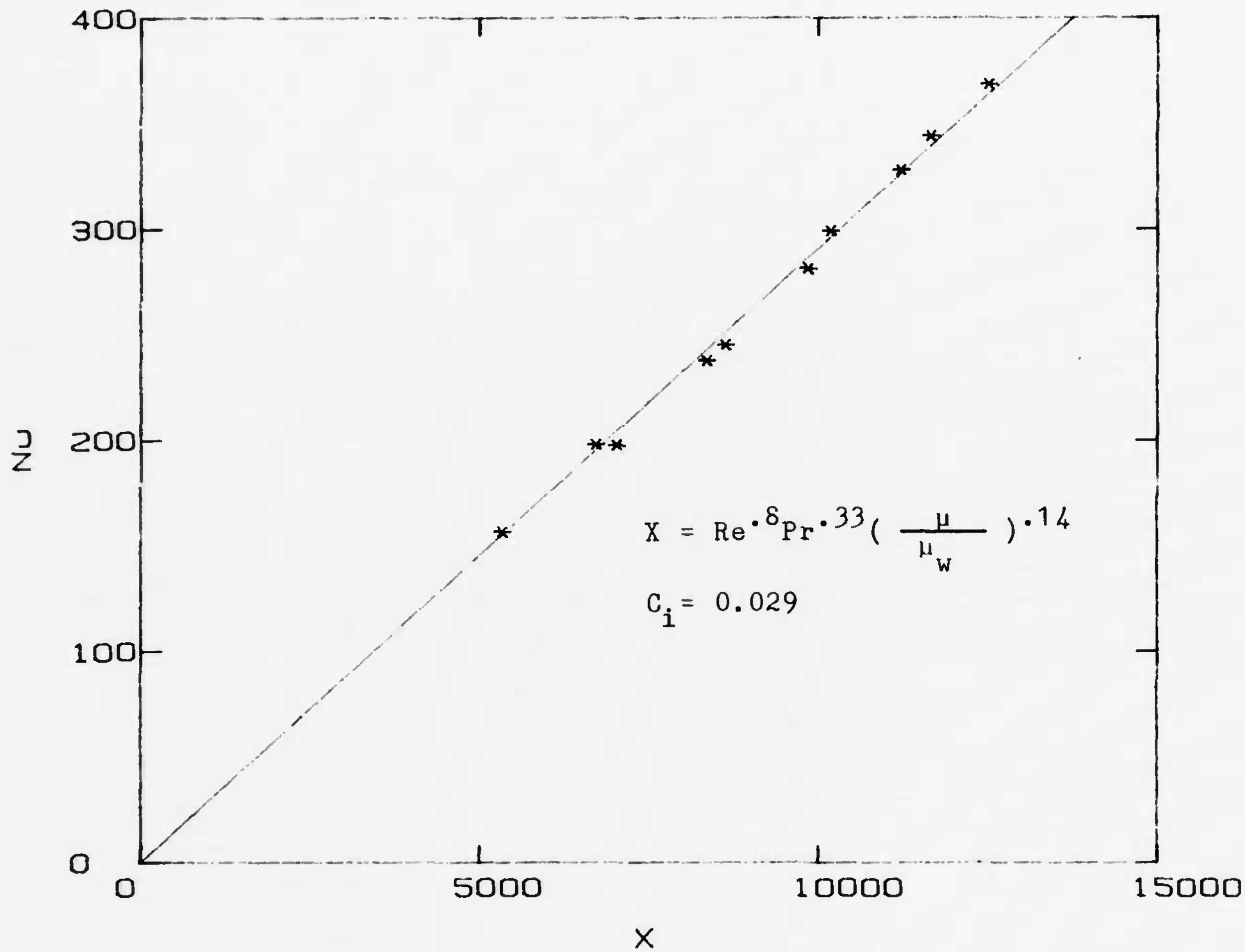


Figure 5.1 Sieder-Tate Paramater Plot

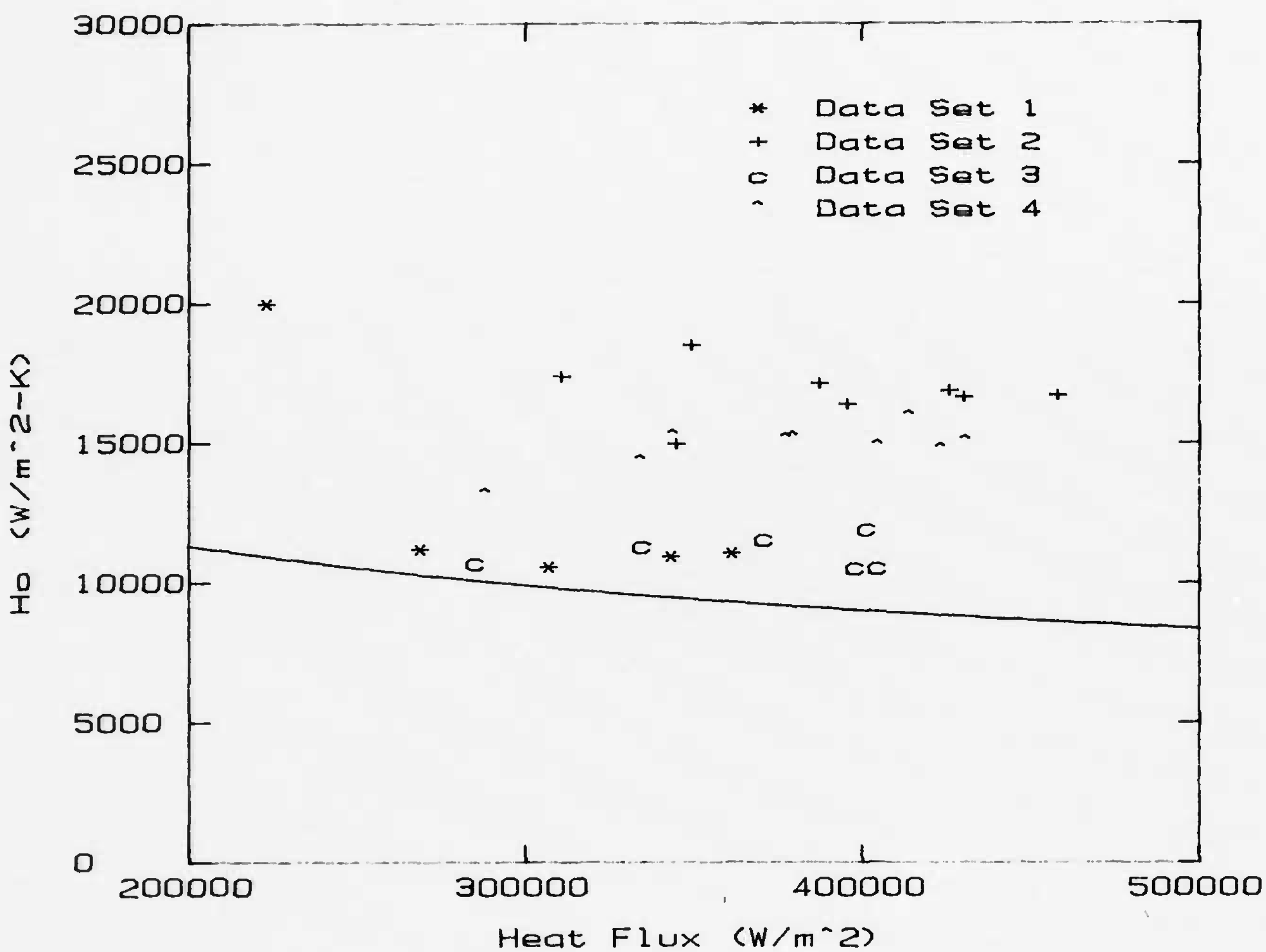


Figure 5.2 Condensing Coefficient Plot

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. An experimental apparatus that allows the study of condensation heat transfer of steam on a single, horizontal tube has been designed, constructed and instrumented.

2. The water-side heat-transfer coefficient was established using the Sieder-Tate correlation with a leading coefficient of 0.029 ± 0.001.

3. An analysis scheme to establish the condensing heat-transfer coefficient has been outlined, and data acquisition/reduction programs have been written and tested.

B. RECOMMENDATIONS

1. To prevent leaking, install Swagelok fittings with Teflon ferrules into the dump condenser lines penetrating the stainless base of the dump condenser section.

2. Rig suspension cables to remove the dump condenser section by attaching them in the ceiling using metal studs.

3. Install a thermopile at the outlet of the test condenser tube as a second means of measuring the cooling water temperature rise across the test section.

4. Use a commutating bridge to accurately determine boiler heater resistance over the full range of power settings.

5. Install a nitrogen cold trap on the mechanical vacuum pump.

6. Install a permanent drain line on the cooling water reservoir to replace the temporary siphon tube.

7. Replace the extension wire from the ice bath to the data acquisition system with thermocouple-quality copper wire.

8. After recommendation No. 1 above is completed, check the system for leak tightness under vacuum conditions.

9. Complete experimentation to determine the condensing heat-transfer coefficient at 1 atmosphere as well as under vacuum conditions.

APPENDIX A

SAMPLE CALCULATIONS

1. INSIDE HEAT-TRANSFER COEFFICIENT

A set of calculations was performed to verify data reduction program SIEDER. One data point was selected arbitrarily from data set 10.

a. Given the following inlet and outlet temperatures, compute average cooling water temperature.

$T_1 = 23.94^\circ C$

$T_2 = 26.32^\circ C$

$T_b = (23.94 + 26.32)/2 = 25.13^\circ C$

b. Compute average wall temperature.

$T_w = (T_{w1}+T_{w2}+T_{w3}+T_{w4}+T_{w5}+T_{w6})/6 = 62.64^\circ C$

c. Compute water velocity.

Flow meter reading = 25% and from the calibration curve, $V_w = 4.5$ ft/s or $V_w = 1.37$ m/s.

From Reference 16, Table A.6 at 300 K the following properties are found:

$P_r = 5.83$

$\mu_f = 855E-6\ N\text{-}s/m^2$

$C_p = 4.179\ kJ/Kg\text{-}K$

$K_f = 613E-3\ W/m\text{-}K$

$\nu_f = 1.003E-3\ m^3/kg$

d. Compute mass flow rate of cooling water.

$A = \pi D_i^2/4$

$\dot{m} = V_w\ A/\nu = 0.173\ kg/s$

e. Compute heat transferred to cooling water.

$Q = \dot{m}\ C_p\ (T_1 - T_2)$

$Q = 1721\ W$

f. Compute average inside wall temperature.

$T_w = Q \ln (D_o/D_i)\ /2\ \pi\ k_f\ L$ Reference 17

$T_w = 2.16^{\circ}C$

$T_{wi} = T_w - 0.5\ \Delta T_w$

$T_{wi} = 61.56^{\circ}C$

g. Compute log mean temperature difference.

$LMTD = (T_2 - T_1)/\ln \left[(T_{wi} - T_1)/(T_{wi} - T_2)\right]$

h. A fin efficiency is assumed to be 20% for first interaction.

i. Compute heat-transfer coefficient.

$h_i = Q/\pi\ D_i\ (L + L_1 * \eta_1 + L_2 * \eta_2)\ LMTD$

$h_i = 7772\ W/m^2\text{-}K$

j. Compute Nusselt number.

$Nu = h_i D_i / k_f$

Nu = 161 --------- first iteration

k. Calculate fin efficiency.

$P_1 = 2\pi\ D_o = 0.1197\ m$

$P_2 = 2\pi\ D_r = 0.100\ m$

$A_1 = \pi\ D_o\ (D_o - D_i) = 0.00038\ m^2$

$A_2 = \pi\ D_r\ (D_r - D_i) = 1.6\ E\text{-}4\ m^2$

$m_1 = \sqrt{h_i\ P_1 / k_f A_1}$

$m_1 = 79.74$

$m_2 = \sqrt{h_i\ P_2 / k_f A_2}$

$m_2 = 112.32$

$\eta_1 = \tanh\ (m_1\ L_1)/m_1\ L_1$

$\eta_1 = .2079$

$\eta_2 = .2913$

l. Recalculate heat-transfer coefficient.

$h_i = 7589.9\ W/m^2\text{-}K$

m. Recalculate Nusselt number and compare to previous calculated value.

$Nu = 157.24$

This value for the Nusselt number agrees within 0.3% of the computer generated value ($Nu_c = 156.7$).

2. CONDENSATION HEAT-TRANSFER COEFFICIENT

A set of calculations was performed to verify the data reduction program NSFDRP. One data point was selected from data run 1.

a. Given the following inlet and outlet cooling water temperatures, compute average water temperature.

$T_1 = 30.06^\circ C$

$T_2 = 32.53^\circ C$

$\overline{T}_b = (T_1 + T_2)/2 = 31.3^\circ C$

$T_s = 96.7^\circ C$

b. Compute water velocity.

Flow meter reading = 30% and from the calibration curve $V_w = 1.64$ m/s

c. Compute mass flow rate of cooling water.

From Reference 16, Table A.6 at 304K the following properties are found:

$Pr = 5.29$

$\mu = 0.781\ E\text{-}3\ N\text{-}s/m^2$

$C_p = 4.178\ kJ/kg\text{-}K$

$k = 0.62\ W/m\text{-}K \quad vw = 1.005\ E\text{-}3\ m^3/kg$

$A = \pi D_i^{\,2}/4$

$A = 1.267\ E\text{-}4\ m^2$

$\dot{m} = V_w\ A/v$

$\dot{m} = .2067\ kg/s$

d. Compute heat transferred to cooling water.

$Q = 2133\ W$

e. Compute LMTD.

$LMTD = (T_2 - T_1)/\ln\left[(T_s - T_1)/(T_s - T_2)\right]$

$LMTD = 65.40°C$

f. Compute overall heat-transfer coefficient based on outside area.

$A_o = \pi D_o L$

$U_o = Q/A_c\ LMTD$

$U_o = 4086.71\ W/m^2\text{-}K$

g. Compute wall resistance based on outside area.

$R_m = D_o\ \ln(D_o/D_i)/2\ k_{cu}$

$R_m = 1.003\ E\text{-}5\ m^2\text{-}K/W$

h. Compute Reynolds number of cooling water.

$Re_w = V_w\ D_i/\nu_f$

$Re_w = 26535$

i. Assume fin efficiencies of $\eta_1 = 0.20$ and $\eta_2 = 0.24$ and assuming $(\mu/\mu_w)^{0.14} = 1.0$

j. Compute inside heat-transfer coefficient.

$h_i = (k_w C_i/D_i) Re_w^{.8} Pr^{.333} (\mu/\mu_w)^{.14}$

$h_i = 8533.72$ W/m^2-K

k. Calculate fin efficiency using previously-calculated heat-transfer coefficient from j.

$m_1 = 83.56$ m^{-1}

$m_2 = 117.70$ m^{-1}

$\eta_1 = 0.20$

$\eta_2 = 0.24$

l. Calculate cooling water rise.

$\overline{T}_w = T_b + \Delta T_w = 72°C$

From Reference 16 at 345 K, $\nu_w = 389E-6$ N-S/m^2

$(\mu/\mu_w)^{0.14} = 1.1$

m. Recalculate heat transfer coefficient and iterate if not within 1% of the value found in j.

$h_i = 9387$ W/m^2-K

n. Calculate condensation heat-transfer coefficient.

$$h_o = \frac{1}{\dfrac{1}{U_o} - \dfrac{D_o L}{D_i (L+\eta_1 L_1+\eta_2 L_2) h_i} - R_m}$$

$h_o = 10405$ W/m^2-K

This value for the condensation heat-transfer coefficient agrees within 1% of the computer generated value ($h_{oc} = 10550$).

APPENDIX B

SYSTEM STARTUP PROCEDURES

1. Familiarize all valve numbers by referring to Figure 2.1.

2. Fill boiler with distilled water to a level 4 inches below top of sight glass.

    a. Start vacuum pump or air ejector.

    b. Open suction line supply valve (3).

    c. Allow vacuum pump/air ejector to run until 15 inches Hg of vacuum is attained.

    d. Close suction line supply valve (3).

    e. Shut down vacuum system.

    f. Open discharge on distilled water tank.

    g. Open distilled water supply line valve (6).

    h. Close distilled water supply line valve (6) when boiler is filled to 4 inches below the top of the sight glass.

3. For vacuum operations, start vacuum pump/air ejector then open suction line supply valve (3) until desired pressure is reached. Suction line supply valve may be throttled to maintain pressure.

4. Energize viewing window heater and adjust rheostat to 110. Open air supply valve (9) about ½ turn. The air supply may require further adjustments to keep viewing window clear.

5. Open dump condenser supply valve (2) fully.

6. Fill cooling water reservoir.

   a. Open reservoir stop valve (10).

   b. Open test section throttle valve (11).

   c. Open reservoir fill valve and allow tank to fill to about 101.6 mm (4 in) from the top.

   d. Close reservoir stop valve.

   e. Energize cooling water circulation pump. The switch is located above the pump.

7. Shut the following power supply breakers:

   a. Panel p-5 switch 3.

   b. Switch 3 on side of control panel.

   c. Switch 1 on front panel.

8. Increase boiler heater voltage to a maximum of 200 volts during warmup; about 15 minutes. When operating under vacuum conditions use a lower voltage to limit vibration of glass piping.

9. As steam is generated, air is expelled through a relief valve. System pressure should never be allowed to exceed 10 psig.

10. Once steam reaches condenser test section (about 30 minutes following startup), full power operation may begin.

11. The apparatus should be allowed to steam for 30 minutes prior to taking any data.

APPENDIX C

SYSTEM SHUTDOWN PROCEDURES

1. Decrease boiler heater voltage to zero.

2. Open all three circuit breakers.

3. Secure view window heater rheostat switch; allow air to flow for about 15 minutes longer.

4. Secure cooling water circulation pump.

5. Close cooling water throttle valve.

6. Close dump condenser supply valve.

7. If in use, secure vacuum suction supply valve followed by vacuum pump/air ejector.

8. For cleaning purposes only, the boiler may be drained by unscrewing the Swaglok nut housing the condensate return thermocouple. The Teflon ferrules require only hand tightening.

APPENDIX D

TEST SECTION INSTALLATION PROCEDURES

1. Install outlet nylon holder, mixing chamber and return line onto provide 6.35 mm (0.25 in) diameter bolts and tighten.
2. Place clean test tube into inlet nylon holder and carefully slide holder and test tube into condenser test section snugly.
3. Align test tube to have one thermocouple channel vertical.
4. Carefully slide thermocouples into channels.
5. Ensure wires are straight and lined up with markings on inlet nylon holder and tape into place.
6. Position nylon thermocouple wire retainer over wires.
7. Place inlet nylon holder over end of test tube and tighten all bolts.
8. Energize circulation pump and check for leakage around connections both inside and outside test section.

APPENDIX E

THERMOCOUPLE CALIBRATION

1. EQUIPMENT USED

a. Thermocouple wire

Copper-constantan, 0.245 mm (0.01 in) Teflon coated wire was used for all thermocouples. (Omega Catalogue)

b. Calibration bath

A Rosemount Engineering Co. Model 913A calibration bath shown schematically in Figure A.1 was used.

1) Heating: Electrical

2) Cooling: Liquid Nitrogen

Note:

Once a desired temperature is reached, the temperature is held constant by rapid cycling between heating and cooling. The manufacturer rates the temperature bath fluctuation to be less than $0.01^{\circ}C$. Observations during the calibration procedure showed bath temperature fluctuation to be less than $0.025^{\circ}C$ ($1.0 \mu V$).

c. Thermocouple readout

An HP 3054A Automatic Data Acquisition/Control System with resolution of $0.1\ \mu V$ was used to obtain data.

d. Reference Point

A reference junction was placed in a 0.15 m Dia X 0.28 m high Thermos flask filled with finely-crushed ice.

e. Temperature measurement

Mercury-in-glass thermometers with a resolution of 0.1°C were used. A total of four thermometers were used with the following ranges: 0-25, 25-54, 50-76 and 76-104°C.

2. PREPARATION

a. Procedure

Two thermocouples were prepared, one at the beginning and the other at the end of a reel of thermocouple wire, using the following procedure:

1) The Teflon insulation was removed for a length of about 4 mm from one end of a 2 m long piece of wire and a thermocouple bead was made using a Dynatech Corporation thermocouple welder.
2) The other end of the thermocouple wire was soft soldered to a pair of heavy duty copper wires.
3) Heat shrink insulation was placed on the soldered end.

b. Reference point

The thermocouple reference junctions were placed in a 5 cm test tube and then into a thermos flask containing finely crushed ice as shown in Figure A.1.

c. Thermometers

Thermometers were completely immersed in the calibration bath as recommended by the manufacturer.

d. Analysis

A short computer program (TC_CAL) was written to accept the thermocouple readings through the HP data acquisition system, and the bath temperature through the keyboard. This program prints all data as well as stores the data on a computer disk. A listing of the computer program is provided in Appendix G.

3. CALIBRATION PROCEDURE

a. The bath temperature was set at about 15°C.

b. A constant temperature is reached when rapid cycling of heating and cooling occurs, but wait three minutes to enter data.

c. Enter the bath temperatures, as measured by the mercury-in-glass thermometer, into the keyboard. Immediately following the data entry, the computer will read the thermocouple EMF automatically and print the bath temperature and thermocouple EMF (μV).

d. When the computer prompts for more data, increase bath temperature by about 10°C and repeat the above procedure up to about 95°C.

e. Repeat the above procedure for decreasing temperatures.

4. CALIBRATION CURVE

a. A least-squares technique was used to generate a third order polynomial in the form of:

$$T = a_1E+a_2E^2+a_3E^3$$

T is the temperature in degrees celsius and E is the thermocouple reading in microvolts.

b. Values generated for the coefficients are:

$a_1 = 0.02635$

$a_2 = -9.735$ E-7

$a_3 = 6.577$ E-11

c. Figure A.2 is a sample printout of calibration data.

d. Figure A.3 is a graphical representation of calibration data.

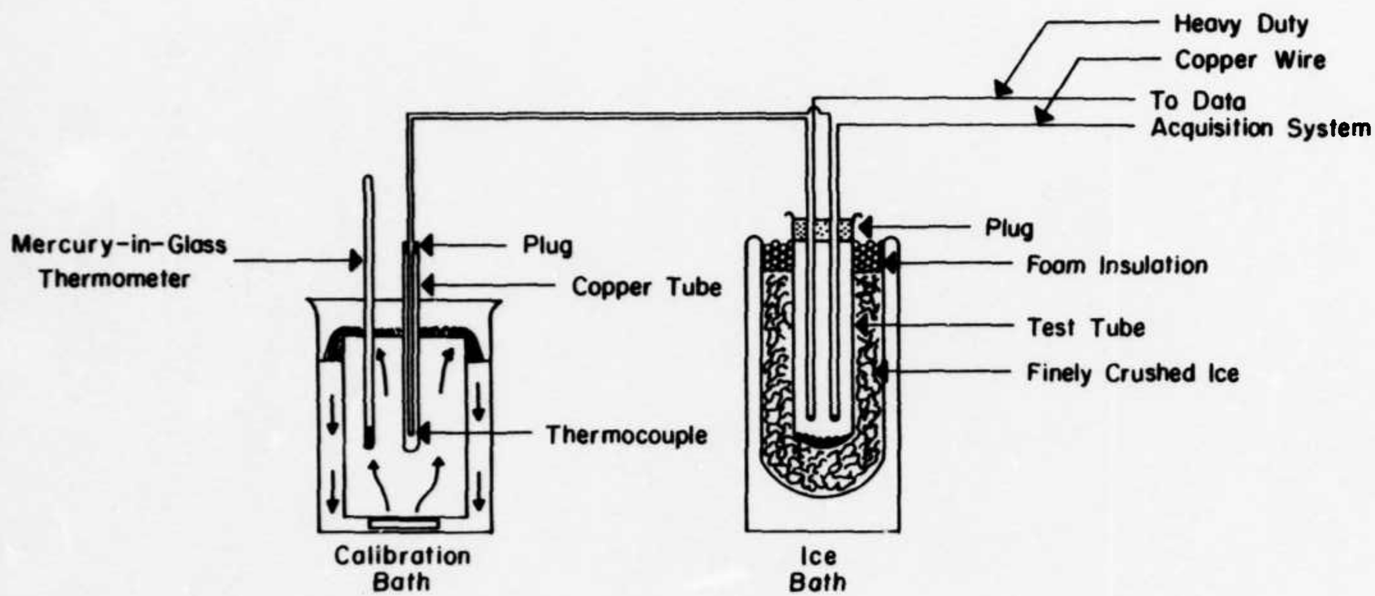


Figure E.1 Schematic of Calibration Bath.

Month, date and time:03:16:20:20:30

Bath Temp (Deg C)	Emf(0) (Micro V)	Emf(1) (Micro V)
13.06	503.0	503.2
24.33	955.0	956.0
35.33	1409.5	1409.0
46.72	1889.8	1891.1
59.50	2442.9	2442.4
72.06	2996.4	2995.7
84.78	3575.8	3575.1
94.00	3998.8	3998.1
93.22	3963.9	3963.0
82.89	3488.8	3488.2
66.89	2767.8	2766.9
54.33	2216.9	2215.8
42.06	1691.7	1690.9
30.67	1213.4	1212.4
20.72	806.5	806.0
13.06	502.5	502.0

16 runs were stored in file CAL_DATA

Figure E.2 Calibration Printout.

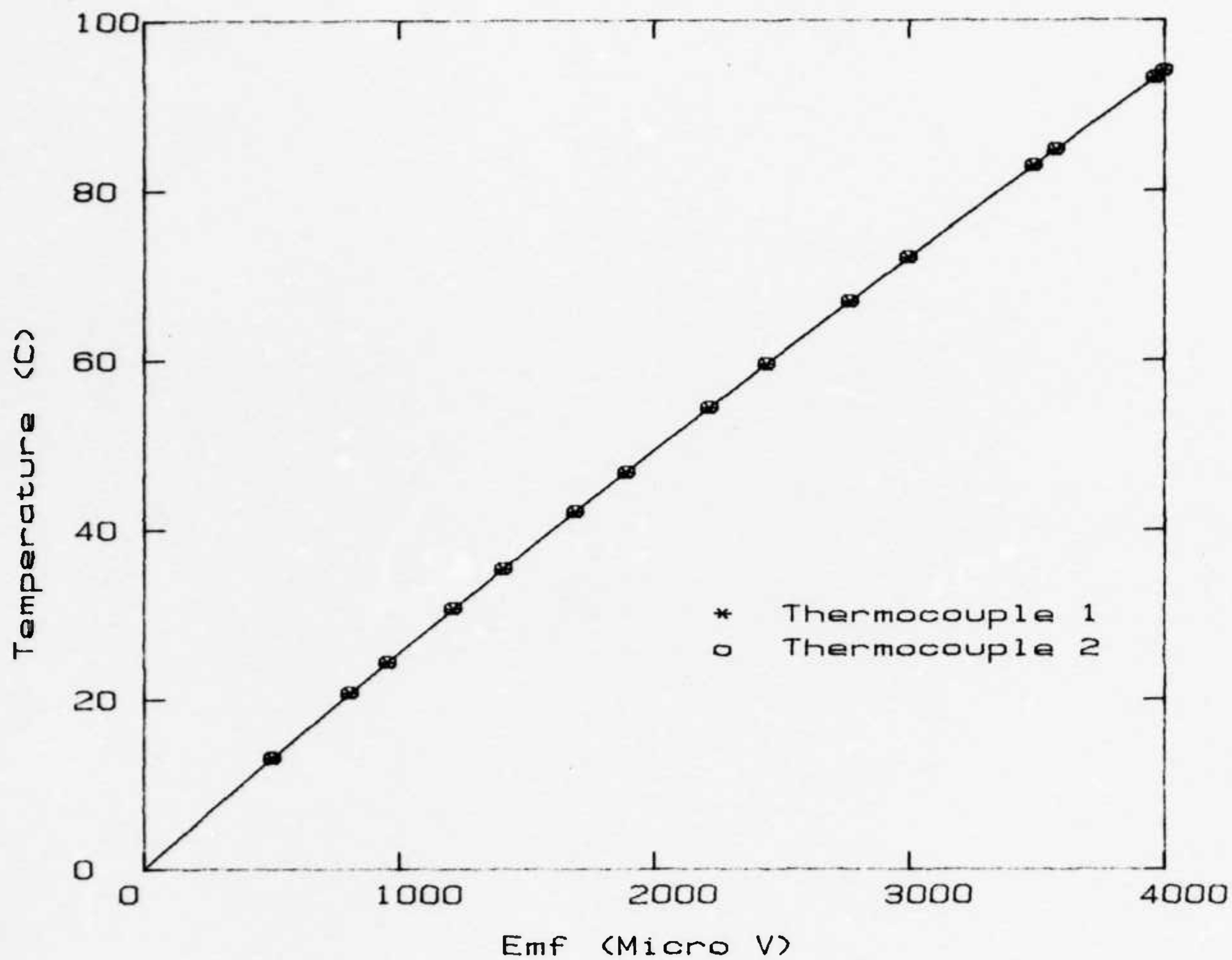


Figure E.3 Thermocouple Calibration Curve.

APPENDIX F

TEST TUBE CLEANING PROCEDURES

----Caution----

The following mixture is highly toxic and very irritant when contacted by the skin. Be very careful not to splash the solution in any way. Wear protective gloves and eye protection when the actual cleaning is being conducted.

1. Ensure the surface of the tube is smooth by placing in lathe and polishing with copper cleaner (Brasso) and a clean rag.

2. While still in the lathe, wipe completely with acetone followed by ethyl alcohol.

3. Prepare a solution of equal parts of 50% sodium hydroxide solution (commercially prepared, available through MCB Manufacturing Chemists Inc., Cincinnati, OH) and ethyl alcohol. About 4 ounces each mixed in a shallow stainless-steel pan is sufficient. The sodium hydroxide will precipitate out of solution and form a white paste.

4. Heat the mixture to about 80°C, but try to avoid spattering. The white pasty texture os the solution should now dissolve into a clear liquid.

5. Completely immerse the tube into the mixture and scrub the entire surface with a bristle brush (old tooth-brushes work fine).

6. Rinse with tap water followed by distilled water.

7. Allow the tube to remain in distilled water until ready for installation.

8. The nylon holders should also be cleaned with the mixture.

9. The test tube should be installed as soon as possible after cleaning.

APPENDIX G

COMPUTER PROGRAM LISTINGS

```
100! FILE NAME: TC_CAL
110! REVISED:   June 1, 1983
120!
130  DIM Emf(1)
140  PRINTER IS 701
150  BEEP
160  INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
170  OUTPUT 709:"TD";Date$
180  OUTPUT 709;"TD"
190  ENTER 709;Date$
200  PRINT USING "12X,""Month, date and time:"",14A":Date$
210  BEEP
220  INPUT "GIVE A NAME FOR DATA FILE",D_file$
230  CREATE BDAT D_file$,5
240  ASSIGN @File TO D_file$
250  J=0
260  PRINT " "
270  PRINT USING "12X,""Bath Temp     Emf(0)     Emf(1)"""
280  PRINT USING "12X,"" (Deg C)    (Micro V)  (Micro V)"""
290 Repeat: !
300  BEEP
310  INPUT "ENTER BATH TEMPERATURE (DEG F)",T_bath
320  T_bath=(T_bath-32.)/1.8
330  OUTPUT 709;"AR AF20 AL21"
340  OUTPUT 722:"F1 R1 T1 Z1 FL1"
350  FOR I=0 TO 1
360  OUTPUT 709;"AS SA"
370  ENTER 722:Emf(I)
380  Emf(I)=ABS(Emf(I))*10^6
390  NEXT I
400  PRINT USING "13X,3D.DD,7X,4D.D,5X,4D.D":T_bath,Emf(*)
410  OUTPUT @File;T_bath,Emf(*)
420  BEEP
430  INPUT "ARE YOU TAKING MORE DATA (1=YES,0=NO)?",Go_on
440  J=J+1
450  IF Go_on=1 THEN Repeat
460  BEEP
470  PRINT " "
480  PRINT USING "12X,DD,"" runs were stored in file "",10A":J,D_file$
490  END
```

```
1000! FILE NAME: NSFDRP
1010 !REVISED:  23 MAY 1983
1020  DIM Emf(10)
1030  Di=.0127
1040  Do=.01905
1050  Dr=.015875
1060  Dssp=.1524
1070  Ax=PI*Dssp`2/4-PI*Do*L  ! TO BE MODIFIED
1080  L=.13335
1090  L1=.060325
1100  L2=.034925
1110  L1=L1+(Do-Di)/4
1120  L2=L2+(Dr-Di)/4
1130  Ci=.029
1140  Kcu=385.
1150  Rm=Do*LOG(Do/Di)/(2*Kcu)
1160  PRINTER IS 701
1170  CLEAR 709
1180  BEEP
1190  INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
1200  OUTPUT 709:"TD";Date$
1210  OUTPUT 709:"TD"
1220  ENTER 709;Date$
1230  PRINT "               Month, date and time :";Date$
1240  BEEP
1250  INPUT "ENTER INPUT MODE (1=3054A,2=FILE)",Im
1260  IF Im=1 THEN
1270  BEEP
1280  INPUT "GIVE A NAME FOR THE RAW DATA FILE",D_file$
1290  CREATE BDAT D_file$,10
1300  ELSE
1310  BEEP
1320  INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D_file$
1330  PRINT " "
1340  PRINT USING "12X,""The following analysis was performed for data in file "
",10A";D_file$
1350  BEEP
1360  INPUT "ENTER THE NUMBER OF RUNS STORED",Nrun
1370  END IF
1380  BEEP
1390  INPUT "GIVE A NAME FOR PLOT DATA FILE",P_file$
1400  CREATE BDAT P_file$,5
1410  ASSIGN @File TO D_file$
1420  ASSIGN @Filep TO P_file$
1430  J=0
1440 Repeat:!
1450  J=J+1
1460  IF Im=1 THEN
1470  BEEP
1480  INPUT "ENTER FLOWMETER READING",Fm
1490  OUTPUT 709:"AR AF20 AL30"
1500  OUTPUT 722:"F1 R1 T1 Z1 FL1"
1510  OUTPUT 709:"AS SA"
1520  ENTER 722;Bpv
1530  FOR I=0 TO 10
1540  OUTPUT 709:"AS SA"
1550  IF I>4 THEN
1560  Se=0
1570  FOR K=0 TO 10
```

```
1580  ENTER 722:E
1590  Se=Se+E
1600  NEXT K
1610  Emf(I)=ABS(Se/10)*1.E+6
1620  ELSE
1630  ENTER 722:E
1640  Emf(I)=ABS(E)*1.E+6
1650  END IF
1660  NEXT I
1670  ENTER 722:Emf(I)
1680  OUTPUT 713:"T1R2E"
1690  WAIT 2
1700  ENTER 713:T1
1710  OUTPUT 713:"T2R2E"
1720  WAIT 2
1730  ENTER 713:T2
1740  IF J=1 THEN
1750  BEEP
1760  INPUT "ENTER MANOMETER READING (mm Hg)",Phg
1770  BEEP
1780  INPUT "ENTER HEIGHT OF MANOMETER WATER COLUMN",Pwater
1790  END IF
1800  ELSE
1810  ENTER @File:Emf(*),Fm,T1,T2,Phg,Pwater,Bpv
1820  END IF
1830  Tsteam=0
1840  FOR I=0 TO 1
1850  Tsteam=Tsteam+.5*FNTvsv(Emf(I))
1860  NEXT I
1870  Twm=0.
1880  FOR I=0 TO 5
1890  Tw(I)=FNTvsv(Emf(I+5))
1900  Twm=Twm+Tw(I)
1910  NEXT I
1920  Twm=Twm/6
1930  Tcon=FNTvsv(Emf(10))
1940  Psat=FNPvst(Tsteam)
1950  Ptest=(Phg+Pwater/13.6)*133.322
1960  IF J=1 THEN
1970  Vst=FNVvst(Tsteam)
1980  Ppng=(Ptest-Psat)/Ptest
1990  Ppst=1-Ppng
2000  Mfng=Ppng/(287*(Tsteam+273.15)/(Vst*Ptest)+Ppng)
2010  Vfng=Mfng/(1.608-.608*Mfng)
2020  Mfng=Mfng*100
2030  Vfng=Vfng*100
2040  BEEP
2050  PRINT " "
2060  PRINT USING "12X,""Measured pressure                                   = "",D.3D
E,"" (Pa)""":Ptest
2070  PRINT USING "12X,""Pressure corresponding to measured steam temp = "",D.3D
E. "" (Pa)""":Psat
2080  PRINT USING "12X,""Noncondensable gas concentration              ="",D.D,"" (
Vol %)""":Vfng
2090  PRINT USING "12X,""Noncondensable gas concentration              ="",DD.D,""(
Mass %)""":Mfng
2100  IF Mfng>.5 THEN
2110  BEEP
2120  PRINT " "
2130  IF Im=1 THEN
```

```
2140  BEEP
2150  PRINT " "
2160  PRINT USING "10X,""Energize the vacuum system """
2170  BEEP
2180  INPUT "OK to accept the present run (1=YES,0=NO)?",Ok
2190  IF Ok=0 THEN
2200  BEEP
2210  DISP "NOTE: THE PRESENT DATA RUN WILL BE DISCARDED!! "
2220  WAIT 5
2230  GOTO 1460
2240  END IF
2250  END IF
2260  END IF
2270  END IF
2280  IF Im=1 THEN OUTPUT @File;Emf(*),Fm,T1,T2,Phg,Pwater,Bps
2290! ANALYSIS BEGINS
2300  Tavg=(T1+T2)*.5
2310  Cpw=FNCpw(Tavg)
2320  Rhow=FNRhow(Tavg)
2330  Mf=Fm*.02451*.3048^3/100
2340  Md=Mf*Rhow
2350  Vw=Mf/(PI*Di^2/4)
2360  Q=Md*Cpw*(T2-T1)
2370  Qp=Q/(PI*Do*L)
2380  Two=Twm+Qp*Rm*.5
2390  Dtf=Tsteam-Two
2400  Kw=FNKw(Tavg)
2410  Muw=FNMuw(Tavg)
2420  Rew=Rhow*Vw*Di/Muw
2430  Prw=FNPrw(Tavg)
2440  Fe1=0.
2450  Fe2=0.
2460  Cf=1.
2470  Hi=Kw*Ci/Di*Rew^.8*Prw^.3333*Cf
2480  Dt=Q/(PI*Di*(L+L1*Fe1+L2*Fe2)*Hi)
2490  Cfc=(Muw/FNMuw(Tavg+Dt))^.14
2500  IF ABS((Cfc-Cf)/Cfc)>.01 THEN
2510  Cf=(Cf+Cfc)*.5
2520  GOTO 2470
2530  END IF
2540  P1=PI*(Di+Do)
2550  A1=(Do-Di)*PI*(Di+Do)*.5
2560  M1=(Hi*P1/(Kcu*A1))^.5
2570  P2=PI*(Di+Dr)
2580  A2=(Dr-Di)*PI*(Di+Dr)*.5
2590  M2=(Hi*P2/(Kcu*A2))^.5
2600  Lmtd=(T2-T1)/LOG((Tsteam-T1)/(Tsteam-T2))
2610  Uo=Q/(Lmtd*PI*Do*L)
2620  Fe1=FNTanh(M1*L1)/(M1*L1)
2630  Fe2=FNTanh(M2*L2)/(M2*L2)
2640  Ho=1/(1/Uo-Do*L/(Di*(L+L1*Fe1+L2*Fe2)*Hi)-Rm)
2650  Dtc=Q/(PI*Di*(L+L1*Fe1+L2*Fe2)*Hi)
2660  IF ABS((Dtc-Dt)/Dtc)>.01 THEN 2470
2670  Troom=FNTvsv((Emf(3)+Emf(4))*.5)
2680  PRINT "UO=";Uo
2690  Hos=Q/(PI*Do*L*(Tsteam-Two))
2700  PRINT "HO_STAR=";Hos
2710  Hfg=FNHfg(Tsteam)
2720  Tfilm=(Tsteam+Two)*.5
2730  Kf=FNKw(Tfilm)
```

```
2740  Rhof=FNRhow(Tfilm)
2750  Muf=FNMuw(Tfilm)
2760  Hnu=.725*(Kf^3*Rhof^2*9.81*Hfg/(Muf*Do*Dtf))^.25
2770  Hpq=.651*Kf*(Rhof^2*9.81*Hfg/(Muf*Do*Qp))^.3333
2780  PRINT " "
2790  PRINT USING "12X,""Water velocity              = "",Z.DD,"" (m/S)""";Vw
2800  PRINT USING "12X,""Reynolds number             = "",5D.D";Rew
2810  PRINT USING "12X,""Inside heat-tran coef       = "",5D.D,"" (W/m^2-K)""";Hi
2820  PRINT USING "12X,""Heat flux                   = "",Z.5DE,"" (W/m^2)""";Qp
2830  PRINT USING "12X,""Outside heat-tran coef      = "",5D.D,"" (W/m^2-K)""";Ho
2840  PRINT USING "12X,""Nusselt coefficient         = "",5D.D,"" (W/m^2-K)""";Hnu
2850  PRINT USING "12X,12X,""Nus coef (from heat flux) = "",5D>D,""(W/m^2-K)""";
Hqp
2860  OUTPUT @Filep;Qp,Hos,Hnu
2870  IF Im=1 THEN
2880  BEEP
2890  INPUT "ARE YOU TAKING MORE DATA (1=YES,0=NO)?",Go_on
2900  IF Go_on=1 THEN Repeat
2910  ELSE
2920  IF J<Nrun THEN Repeat
2930  END IF
2940  IF Im=1 THEN
2950  BEEP
2960  PRINT USING "12X,""NOTE: "",DD,"" data runs were stored in file "",10A";J,
D_file$
2970  END IF
2980  BEEP
2990  PRINT " "
3000  PRINT USING "12X,""NOTE: "",DD,""X-Y pairs were stored in plot data file "
",10A";J,P_file$
3010  ASSIGN @File TO *
3020  END
3030  DEF FNPvst(Tsteam)
3040  DIM K(8)
3050  DATA -7.691234564,-26.08023696,-168.1706546,64.23285504,-118.9646225
3060  DATA 4.16711732,20.9750676,1.E9,6
3070  READ K(*)
3080  T=(Tsteam+273.15)/647.3
3090  Sum=0
3100  FOR N=0 TO 4
3110  Sum=Sum+K(N)*(1-T)^(N+1)
3120  NEXT N
3130  Br=Sum/(T*(1+K(5)*(1-T)+K(6)*(1-T)^2))-(1-T)/(K(7)*(1-T)^2+K(8))
3140  Pr=EXP(Br)
3150  P=22120000*Pr
3160  RETURN P
3170  FNEND
3180  DEF FNHfg(T)
3190  Hfg=2497.7389-T*(2.2074+T*(1.7079E-3-2.8593E-6))
3200  RETURN Hfg*1000
3210  FNEND
3220  DEF FNMuw(T)
3230  Mu=1.57609473E-3-T*(3.51198576E-5-T*(3.5835816E-7-1.365586115E-9*T))
3240  RETURN Mu
3250  FNEND
3260  DEF FNVvst(T)
3270  V=58.4525588-T*(1.51508776-T*(.01372746585-T*4.25366711E-5))
3280  RETURN V
3290  FNEND
3300  DEF FNCpw(T)
```

```
3310  Cpw=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
3320  RETURN Cpw*1000
3330  FNEND
3340  DEF FNRhow(T)
3350  Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
3360  RETURN Ro
3370  FNEND
3380  DEF FNPrw(T)
3390  Prw=10^(1.09976605-T*(1.3749326E-2-T*(3.968875E-5-3.45026E-7*T)))
3400  RETURN Prw
3410  FNEND
3420  DEF FNKw(T)
3430  Kw=.5625894+T*(2.2964546E-3-T*(1.509766E-5-4.0581652E-8*T))
3440  RETURN Kw
3450  FNEND
3460  DEF FNTanh(X)
3470  P=EXP(X)
3480  Q=EXP(-X)
3490  Tanh=(P+Q)/(P-Q)
3500  RETURN Tanh
3510  FNEND
3520  DEF FNTvsv(V)
3530  T=V*(.02617334416-V*(9.2447859E-7-V*6.0746642E-11))
3540  RETURN T
3550  FNEND
3560  DEF FNHf(T)
3570  Hf=T*(4.203849-T*(5.88132E-4-T*4.55160317E-6))
3580  RETURN Hf*1000
3590  FNEND
```

```
1000! FILE NAME: SIEDER
1010! REVISED:   May 23. 1983
1020  DIM Emf(10),Tw(5)
1030  Kcu=385
1040! Assign Geometric Variables
1050!
1060  Di=.0127     !Inside Diameter
1070  Do=.01905    !Outside Diameter
1080  Dr=.015875   !Outlet End Diameter
1090  L=.13335     !Condensing Length
1100  L1=.060325   !Inlet End "fin" Length
1110  L2=.034925   !Outlet End "fin" Length
1120  PRINTER IS 701
1130  BEEP
1140  CLEAR 709
1150  INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",B$
1160  OUTPUT 709;"TD";B$
1170 Series:!
1180  OUTPUT 709;"TD"
1190  ENTER 709;A$
1200  PRINT USING "12X,""Month, date and time: "",14A";A$
1210  BEEP
1220  INPUT "ENTER INPUT MODE (1=3054A,2=FILE)",Im
1230  IF Im=1 THEN
1240  BEEP
1250  INPUT "PROVIDE NAME FOR THE DATA FILE",D_file$
1260  CREATE BDAT D_file$,10
1270  ELSE
1280  BEEP
1290  INPUT "PROVIDE NAME OF THE DATA FILE",D_file$
1300  BEEP
1310  INPUT "ENTER THE NUMBER OF RUNS STORED",Nrun
1320  PRINT USING "12X,""The following analysis was performed for data in file "
",10A";D_file$
1330  END IF
1340  BEEP
1350  INPUT "PROVIDE NAME FOR PLOT DATA FILE",Plot$
1360  CREATE BDAT Plot$,5
1370  ASSIGN @File TO D_file$
1380  ASSIGN @Filep TO Plot$
1390  J=0
1400  Sxs=0
1410  Sxy=0
1420  IF Im=1 THEN
1430! READ DATA THROUGH DATA ACQUISITION SYSTEM
1440! IF THE INPUT MODE (Im) = 1
1450  BEEP
1460  INPUT "ENTER FLOWMETER READING",Fm
1470  OUTPUT 709;"AR AF20 AL30"
1480  OUTPUT 722;"F1 R1 T1 Z1 FL1"
1490  FOR I=0 TO 10
1500  OUTPUT 709;"AS SA"
1510  IF I>4 THEN
1520  Se=0
```

```
1530  FOR K=0 TO 9
1540  ENTER 722:E
1550  Se=Se+E
1560  NEXT K
1570  Emf(I)=ABS(Se/10)
1580  ELSE
1590  ENTER 722:E
1600  Emf(I)=ABS(E)
1610  END IF
1620  NEXT I
1630  OUTPUT 713;"T1R2E"
1640  WAIT 2
1650  ENTER 713;T1
1660  OUTPUT 713;"T2R2E"
1670  WAIT 2
1680  ENTER 713:T2
1690  ELSE
1700! READ DATA FROM USER-SPECIFIED FILE IF
1710! INPUT MODE (Im) = 2
1720  ENTER @File;Emf(*),T1,T2,Fm
1730  END IF
1740! Compute Average Bulk Water Temperature
1750  Tavg=(T1+T2)*.5
1760! Compute Average Wall Temperature
1770  Twall=0
1780  FOR I=5 TO 10
1790  Tw(I-5)=FNTvsv(Emf(I))
1800  Twall=Twall+Tw(I-5)
1810  NEXT I
1820  Twall=Twall/6
1830! Compute Thermophysical Properties
1840  Cpw=FNCpw(Tavg)
1850  Rhow=FNRhow(Tavg)
1860  Kw=FNKw(Tavg)
1870  Mf=Fm*.02451*.3048^3/100 !Volume Flowrate of Water (m^3/s)
1880  Md=Mf*Rhow !Mass Flowrate of Water (kg/s)
1890  Vw=Mf/(PI*Di^2/4) !Water Velocity (m/s)
1900  Q=Md*Cpw*(T2-T1) !Heat Transferred to Cooling Water (W)
1910  Dtw=Q*LOG(Do/Di)/(2*PI*Kcu*L) !Temp Drop Across Tube Wall (Deg C)
1920  Twall=Twall-Dtw*.5
1930  Lmtd=(T2-T1)/LOG((Twall-T1)/(Twall-T2))
1940  P1=PI*2*Do !Heat-Transfer Perimeter At Inlet
1950  P2=PI*2*Dr !Heat-Transfer Perimeter At Exit
1960  A1=(Do-Di)*PI*Do !Heat-Transfer Area At Inlet
1970  A2=(Dr-Di)*PI*Dr !Heat-Transfer Area At Exit
1980  Hi=Q/(PI*Di*L*Lmtd)
1990  M1=(Hi*P1/(Kcu*A1))^.5
2000  M2=(Hi*P2/(Kcu*A2))^.5
2010  Fe1=FNTanh(M1*L1)/(M1*L1) !Fin Efficiency At Inlet
2020  Fe2=FNTanh(M2*L2)/(M2*L2) !Fin Efficiency At Exit
2030  Hic=Q/(PI*Di*(L+L1*Fe1+L2*Fe2)*Lmtd)
2040  IF ABS((Hi-Hic)/Hic)>.01 THEN
2050  Hi=(Hic+Hi)*.5
2060  GOTO 1990
2070  END IF
2080  PRINT " "
2090  PRINT USING "12X,""Position number            :   1    2    3    4    5
   6"""""
2100  PRINT USING "12X,""Wall temperature (Deg C) : "",6(DD.DD,1X)":Tw(*)
2110  PRINT USING "12X,""Average wall temperature = "",DD.DD,"" (Deg C)""";Twall
```

```
2120  PRINT USING "12X,""Inlet water temperature  = "",DD.DD,"" (Deg C)""";T1
2130  PRINT USING "12X,""Outlet water temperature = "",DD.DD,"" (Deg C)""";T2
2140  PRINT USING "12X,""Log-mean-temp difference = "",DD.DD,"" (Deg C)""";Lmtd
2150! CALCULATE THE NUSSELT NUMBER
2160  Nu=Hic*Di/Kw
2170  Re=Rhow*Vw*Di/FNMu(Tavg)
2180  Cf=(FNMu(Tavg)/FNMu(Twall))^.14
2190  Prw=FNPrw(Tavg)
2200  X=Re^.8*Prw^.3333*Cf !Compute Sieder-Tate Parameter
2210! COMPUTE COEFFICIENTS FOR THE LEAST-SQUARES-FIT
2220! STRAIGHT LINE
2230  PRINT USING "12X,""Water velocity            =  "",Z.DD,"" (m/S)""";Vw
2240  PRINT USING "12X,""Sieder-Tate parameter     = "",5D.D";X
2250  PRINT USING "12X,""Nusselt number            = "",4D.DD";Nu
2260  OUTPUT @Filep;X,Nu
2270  Sx=Sx+X
2280  Sy=Sy+Nu
2290  Sxs=Sxs+X*X
2300  Sxy=Sxy+X*Nu
2310! STORE RAW DATA IN A USER-SPECIFIED FILE IF
2320! INPUT MODE (Im) = 1
2330  IF Im=1 THEN OUTPUT @File;Emf(*),T1,T2,Fm
2340  BEEP
2350  J=J+1
2360  IF Im=1 THEN
2370  INPUT "ARE YOU TAKING MORE DATA (1=YES,0=NO)?",Go_on
2380  Nrun=J
2390  IF Go_on=1 THEN 1420
2400  ELSE
2410  IF J<Nrun THEN 1420
2420  END IF
2430  Ci=Sxy/Sxs
2440  PRINT " "
2450  PRINT USING "12X,""Sieder-Tate Coefficient  = "",D.4D";Ci
2460  Ac=0.
2470  PRINT " "
2480  PRINT USING "12X,""Least-Squares Line:"""
2490  PRINT USING "14X,""Slope          = "",MD.5DE,";Ci
2500  PRINT USING "14X,""Intercept      = "",MD.5DE,";Ac
2510  IF Im=1 THEN
2520  BEEP
2530  PRINT USING "12X,""NOTE: "",DD,"" data runs were stored in file "",8A";Nru
n,D_file$
2540  END IF
2550  ASSIGN @File TO *
2560  ASSIGN @Filep TO *
2570  END
2580  DEF FNRhow(T)
2590  Ro=1006.35724-T*(.774489-T*(2.262459E-2-T*3.03304E-4))
2600  RETURN Ro
2610  FNEND
2620  DEF FNPrw(T)
2630  Pr=10^(1.09976605-T*(.013759326-T*(3.968875E-5-3.45026E-7*T)))
2640  RETURN Pr
2650  FNEND
2660  DEF FNMu(T)
2670  Mu=1.57609473E-3-T*(3.51198576E-5-T*(3.5835816E-7-T*1.365586115E-9))
2680  RETURN Mu
2690  FNEND
2700  DEF FNKw(T)
```

```
2710  Kw=.572183504477+1.52770121209E-3*T
2720  RETURN Kw
2730  FNEND
2740  DEF FNTvsv(Emf)
2750  V=Emf*10^6
2760  T=V*(.02617334416-V*(9.2447859E-7-V*6.0746642E-11))
2770  RETURN T
2780  FNEND
2790  DEF FNCpw(T)
2800  Cpw=(4.21120858-T*(2.26826E-3-T*(4.42361E-5+T*2.71428E-7)))*1000
2810  RETURN Cpw
2820  FNEND
2830  DEF FNTanh(X)
2840  P=EXP(X)
2850  Q=EXP(-X)
2860  Tanh=(P+Q)/(P-Q)
2870  RETURN Tanh
2880  FNEND
```

```
1000! FILE NAME: PLOT
1010  PRINTER IS 705
1020  BEEP
1030  INPUT "ENTER MINIMUM AND MAXIMUM X-VALUES",Xmin,Xmax
1040  BEEP
1050  INPUT "ENTER MINIMUM AND MAXIMUM Y-VALUES",Ymin,Ymax
1060  BEEP
1070  INPUT "ENTER STEP SIZE FOR X-AXIS",Xstep
1080  BEEP
1090  INPUT "ENTER STEP SIZE FOR Y-AXIS",Ystep
1100  BEEP
1110  PRINT "IN;SP1;IP 2000,2000,8000,7000;"
1120  PRINT "SC 0,100,0,100;TL 2,0;"
1130  Sfx=100/(Xmax-Xmin)
1140  Sfy=100/(Ymax-Ymin)
1150  PRINT "PU 0,0 PD"
1160  FOR Xa=Xmin TO Xmax STEP Xstep
1170  X=(Xa-Xmin)*Sfx
1180  PRINT "PA";X,",0; XT;"
1190  NEXT Xa
1200  PRINT "PA 100,0;PU;"
1210  PRINT "PU PA 0,0 PD"
1220  FOR Ya=Ymin TO Ymax STEP Ystep
1230  Y=(Ya-Ymin)*Sfy
1240  PRINT "PA 0,";Y,"YT"
1250  NEXT Ya
1260  PRINT "PA 0,100 TL 0 2"
1270  FOR Xa=Xmin TO Xmax STEP Xstep
1280  X=(Xa-Xmin)*Sfx
1290  PRINT "PA":X,",100; XT"
1300  NEXT Xa
1310  PRINT "PA 100,100 PU PA 100,0 PD"
1320  FOR Ya=Ymin TO Ymax STEP Ystep
1330  Y=(Ya-Ymin)*Sfy
1340  PRINT "PD PA 100,",Y,"YT"
1350  NEXT Ya
1360  PRINT "PA 100,100 PU"
1370  PRINT "PA 0,-2 SR 1.5,2"
1380  FOR Xa=Xmin TO Xmax STEP Xstep
1390  X=(Xa-Xmin)*Sfx
1400  PRINT "PA":X,",0;"
1410  PRINT "CP -2,-1;LB";Xa;""
1420  NEXT Xa
1430  PRINT "PU PA 0,0"
1440  FOR Ya=Ymin TO Ymax STEP Ystep
1450  Y=(Ya-Ymin)*Sfy
1460  PRINT "PA 0,":Y,""
1470  PRINT "CP -4,-.25;LB";Ya;""
1480  NEXT Ya
1490  BEEP
1500  INPUT "ENTER X-LABEL",Xlabel$
1510  BEEP
1520  INPUT "ENTER Y-LABEL",Ylabel$
1530  PRINT "SR 1.5,2;PU PA 50,-10 CP":-LEN(Xlabel$)/2:"0:LB":Xlabel$:""
1540  PRINT "PA -11,50 CP 0,":-LEN(Ylabel$)/2*5/6:"DI 0,1;LB":Ylabel$:""
1550  PRINT "CP 0,0"
1560 Repeat:!
1570  BEEP
```

```
1580  INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
1590  ASSIGN @File TO D_file$
1600  BEEP
1610  INPUT "ENTER THE BEGINNING RUN NUMBER",Md
1620  BEEP
1630  INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
1640  BEEP
1650  INPUT "SELECT A SYMBOL FOR THE PLOTTER (1=*,2=+,3=c,4=o,5=^)",Sy
1660  PRINT "PU DI"
1670  IF Sy=1 THEN PRINT "SM*"
1680  IF Sy=2 THEN PRINT "SM+"
1690  IF Sy=3 THEN PRINT "SMc"
1700  IF Sy=4 THEN PRINT "SMo"
1710  IF Sy=5 THEN PRINT "SM^"
1720  IF Md>Npairs THEN
1730  FOR I=1 TO (Md-1)
1740  ENTER @File;Xa,Ya
1750  NEXT I
1760  END IF
1770  FOR I=1 TO Npairs
1780  ENTER @File;Xa,Ya
1790  X=(Xa-Xmin)*Sfx
1800  Y=(Ya-Ymin)*Sfy
1810  PRINT "PA",X,Y,";"
1820  NEXT I
1830  BEEP
1840  ASSIGN @File TO *
1850  INPUT "DO YOU HAVE MORE DATA TO BE PLOTTED (1=YES,0=NO)?",Go_on
1860  IF Go_on=1 THEN Repeat
1870  PRINT "PU SM"
1880  BEEP
1890  INPUT "DO YOU LIKE TO DRAW A STRAIGHT LINE?",Go_on
1900  IF Go_on=1 THEN
1910  BEEP
1920  INPUT "ENTER THE SLOPE",S1
1930  BEEP
1940  INPUT "ENTER THE INTERCEPT",Ac
1950  FOR Xa=Xmin TO Xmax STEP (Xmax-Xmin)
1960  Ya=Ac+S1*Xa
1970  Y=(Ya-Ymin)*Sfy
1980  X=(Xa-Xmin)*Sfx
1990  IF Y<0 THEN
2000  Xam=(Ymin-Ac)/S1
2010  X=(Xam-Xmin)*Sfx
2020  Y=0
2030  END IF
2040  IF Y>100 THEN
2050  Xam=(Ymax-Ac)/S1
2060  X=(Xam-Xmin)*Sfx
2070  Y=100
2080  END IF
2090  PRINT "PA",X,Y,"PD"
2100  NEXT Xa
2110  END IF
2120  PRINT "PU SP0"
2130  END
```

```
10 ! FILE NAME: Q_LOSS
20 ! LAST UPDATED: 23 MAY 83
100  PRINTER IS 701
110  CLEAR 709
120  BEEP
130  INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
140  OUTPUT 709;"TD";Date$
150  OUTPUT 709;"TD"
160  ENTER 709;Date$
170  PRINT USING "10X,""Month, date and time: "",14A";Date$
180  BEEP
190  INPUT "ENTER INPUT MODE (1=3054A,2=FILE)",Im
200  IF Im=1 THEN
210  BEEP
220  INPUT "GIVE A NAME FOR DATA FILE",D_file$
230  CREATE BDAT D_file$,15
240  ELSE
250  BEEP
260  INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D_file$
270  BEEP
280  INPUT "ENTER THE NUMBER OF RUNS STORED",Nrun
290  END IF
300  ASSIGN @File TO D_file$
310  BEEP
320  INPUT "GIVE A NAME FOR THE OUTPUT FILE",O_file$
330  CREATE BDAT O_file$,15
340  ASSIGN @Fileo TO O_file$
350  K=0
360  BEEP
370  INPUT "OK TO GO AHEAD (HIT ENTER)",Ok
380  IF Im=1 THEN
390  OUTPUT 709;"AR AF19 AL21"
400  OUTPUT 722;"F1 R1 T1 Z1 FL1"
410  FOR I=0 TO 2
420  OUTPUT 709;"AS SA"
430  ENTER 722;Emf(I)
440  IF I>0 THEN Emf(I)=ABS(Emf(I))*10^6
450  NEXT I
460  Tsteam=FNTvsv((Emf(1)+Emf(2))*.5)
470  OUTPUT 709;"AR AF23 AL24"
480  OUTPUT 722;"F1 R1 T1 Z1 FL1"
490  FOR J=0 TO 1
500  OUTPUT 709;"AS SA"
510  ENTER 722;Emf(J+3)
520  Emf(J+3)=ABS(Emf(J+3))*10^6
530  NEXT J
540  OUTPUT @File;Emf(*)
550  ELSE
560  ENTER @File;Emf(*)
570  END IF
580  Tsteam=FNTvsv((Emf(1)+Emf(2))*.5)
590  Troom=FNTvsv((Emf(3)+Emf(4))*.5)
600  Power=(Emf(0)*100)^2/5.76*1.E-3
610  Dt=Tsteam-Troom
620  PRINT USING "10X,3D.3D,3(DDD.DD,2X)";Power,Tsteam,Troom,Dt
630  K=K+1
640  IF Im=1 THEN
650  BEEP
```

```
660   INPUT "ARE YOU TAKING MORE DATA (1=YES,0=NO)?",Go_on
670   IF Go_on=1 THEN 380
680   ELSE
690   IF K<Nrun THEN 380
700   END IF
710   END
720   DEF FNTvsv(V)
730   T=V*(.02617334416-V*(9.2447859E-7-V*6.0746642E-11))
740   RETURN T
750   FNEND
```

```
Month. date and time: 06:01:14:55:20
The following analysis was performed for data in file DD10

Position number             :   1     2     3     4     5     6
Wall temperature (Deg C)    : 66.92 65.43 62.00 57.65 65.81 58.03
Average wall temperature    = 61.55 (Deg C)
Inlet water temperature     = 23.94 (Deg C)
Outlet water temperature    = 26.32 (Deg C)
Log-mean-temp difference    = 36.42 (Deg C)
Water velocity              =  1.37 (m/S)
Sieder-Tate parameter       =  5342.8
Nusselt number              =  158.72

Position number             :   1     2     3     4     5     6
Wall temperature (Deg C)    : 68.20 66.10 61.57 55.55 65.90 58.93
Average wall temperature    = 61.42 (Deg C)
Inlet water temperature     = 25.36 (Deg C)
Outlet water temperature    = 27.39 (Deg C)
Log-mean-temp difference    = 35.03 (Deg C)
Water velocity              =  1.92 (m/S)
Sieder-Tate parameter       =  7032.7
Nusselt number              =  199.76

Position number             :   1     2     3     4     5     6
Wall temperature (Deg C)    : 68.10 65.85 60.61 54.03 65.49 57.68
Average wall temperature    = 60.48 (Deg C)
Inlet water temperature     = 26.77 (Deg C)
Outlet water temperature    = 28.59 (Deg C)
Log-mean-temp difference    = 32.79 (Deg C)
Water velocity              =  2.47 (m/S)
Sieder-Tate parameter       =  8634.8
Nusselt number              =  247.76

Position number             :   1     2     3     4     5     6
Wall temperature (Deg C)    : 67.70 65.11 59.70 52.58 64.40 56.49
Average wall temperature    = 59.34 (Deg C)
Inlet water temperature.    = 28.28 (Deg C)
Outlet water temperature    = 29.94 (Deg C)
Log-mean-temp difference    = 30.22 (Deg C)
Water velocity              =  3.01 (m/S)
Sieder-Tate parameter       = 10181.6
Nusselt number              =  302.10

Position number             :   1     2     3     4     5     6
Wall temperature (Deg C)    : 66.69 64.08 58.48 51.22 63.06 55.10
Average wall temperature    = 58.04 (Deg C)
Inlet water temperature     = 29.73 (Deg C)
Outlet water temperature    = 31.19 (Deg C)
Log-mean-temp difference    = 27.58 (Deg C)
Water velocity              =  3.56 (m/S)
Sieder-Tate parameter       = 11676.1
Nusselt number              =  347.19

Position number             :   1     2     3     4     5     6
Wall temperature (Deg C)    : 67.18 64.46 58.95 51.63 63.76 55.68
Average wall temperature    = 58.53 (Deg C)
Inlet water temperature     = 31.91 (Deg C)
Outlet water temperature    = 33.28 (Deg C)
```

```
Log-mean-temp difference = 25.93 (Deg C)
Water velocity           =  3.84 (m/S)
Sieder-Tate parameter    = 12518.8
Nusselt number           =  371.81

Position number          :   1     2     3     4     5     6
Wall temperature (Deg C) : 70.32 67.36 62.08 55.23 66.98 59.06
Average wall temperature = 61.84 (Deg C)
Inlet water temperature  = 33.57 (Deg C)
Outlet water temperature = 35.09 (Deg C)
Log-mean-temp difference = 27.51 (Deg C)
Water velocity           =  3.29 (m/S)
Sieder-Tate parameter    = 11223.3
Nusselt number           =  331.04

Position number          :   1     2     3     4     5     6
Wall temperature (Deg C) : 74.00 71.28 65.83 58.91 70.63 62.82
Average wall temperature = 65.70 (Deg C)
Inlet water temperature  = 35.46 (Deg C)
Outlet water temperature = 37.16 (Deg C)
Log-mean-temp difference = 29.38 (Deg C)
Water velocity           =  2.74 (m/S)
Sieder-Tate parameter    =  9850.0
Nusselt number           =  284.11

Position number          :   1     2     3     4     5     6
Wall temperature (Deg C) : 77.43 74.65 69.49 62.86 74.08 66.46
Average wall temperature = 69.42 (Deg C)
Inlet water temperature  = 37.27 (Deg C)
Outlet water temperature = 39.19 (Deg C)
Log-mean-temp difference = 31.18 (Deg C)
Water velocity           =  2.19 (m/S)
Sieder-Tate parameter    =  8354.8
Nusselt number           =  240.23

Position number          :   1     2     3     4     5     6
Wall temperature (Deg C) : 80.70 77.96 73.09 67.18 77.57 70.37
Average wall temperature = 73.22 (Deg C)
Inlet water temperature  = 38.92 (Deg C)
Outlet water temperature = 41.23 (Deg C)
Log-mean-temp difference = 33.12 (Deg C)
Water velocity           =  1.64 (m/S)
Sieder-Tate parameter    =  6722.9
Nusselt number           =  200.30

Sieder-Tate Coefficient  =  .0294

Least-Squares Line:
  Slope         =  2.93533E-02
  Intercept     =  0.00000E+00
```

```
Month, date and time :05:30:15:27:15

The following analysis was performed for data in file DR1

Measured pressure                                = 9.579E+04 (Pa)
Pressure corresponding to measured steam temp    = 9.010E+04 (Pa)
Noncondensable gas concentration                 =   5.8 (Vol %)
Noncondensable gas concentration                 =   9.0 (Mass %)


Water velocity               = 0.82 (m/S)
Reynolds number              = 13139.2
Inside heat-tran coef        =  5356.2 (W/m^2-K)
Overall-heat-trans coef      =  3393.6 (W/m^2-K)
Heat flux                    = 2.22899E+05 (W/m^2)
Outside heat-tran coef       = 19990.5 (W/m^2-K)
Nusselt coefficient          = 11304.5 (W/m^2-K)
Nus coef (from heat flux)    = 10797.9 (W/m^2-K)

Water velocity               = 1.64 (m/S)
Reynolds number              = 26418.9
Inside heat-tran coef        =  9074.3 (W/m^2-K)
Overall-heat-trans coef      =  4109.5 (W/m^2-K)
Heat flux                    = 2.68764E+05 (W/m^2)
Outside heat-tran coef       = 11186.9 (W/m^2-K)
Nusselt coefficient          = 10320.1 (W/m^2-K)
Nus coef (from heat flux)    = 10005.0 (W/m^2-K)

Water velocity               = 2.47 (m/S)
Reynolds number              = 40022.4
Inside heat-tran coef        = 12466.1 (W/m^2-K)
Overall-heat-trans coef      =  4725.9 (W/m^2-K)
Heat flux                    = 3.06851E+05 (W/m^2)
Outside heat-tran coef       = 10550.9 (W/m^2-K)
Nusselt coefficient          =  9822.2 (W/m^2-K)
Nus coef (from heat flux)    =  9484.8 (W/m^2-K)

Water velocity               = 3.29 (m/S)
Reynolds number              = 53980.1
Inside heat-tran coef        = 15667.3 (W/m^2-K)
Overall-heat-trans coef      =  5331.5 (W/m^2-K)
Heat flux                    = 3.43200E+05 (W/m^2)
Outside heat-tran coef       = 10926.6 (W/m^2-K)
Nusselt coefficient          =  9511.1 (W/m^2-K)
Nus coef (from heat flux)    =  9075.4 (W/m^2-K)

Water velocity               = 3.84 (m/S)
Reynolds number              = 63586.5
Inside heat-tran coef        = 17728.9 (W/m^2-K)
Overall-heat-trans coef      =  5652.2 (W/m^2-K)
Heat flux                    = 3.61307E+05 (W/m^2)
Outside heat-tran coef       = 11060.4 (W/m^2-K)
Nusselt coefficient          =  9359.5 (W/m^2-K)
Nus coef (from heat flux)    =  8889.1 (W/m^2-K)

NOTE:  5 X-Y pairs were stored in plot data file PDR1
```

LIST OF REFERENCES

1. Steam Turbine Condenser, Report No. 619, National Engineering Laboratory, East Kilbride, Glasgow, U.K., August, 1976.

2. Junkhan, G.H., Bergles, A.E., and Webb, R.L., "Research Workshop on Energy Conservation Through Enhanced Heat Transfer," HTL-21, Iowa State University, Ames, Iowa, May, 1979.

3. Marto, P.J., and Nunn, R.H., Proceedings of the Workshop on Modern Developments in Marine Condensers, Naval Postgraduate School, Monterey, California, March, 1980.

4. Bergles, A.E., "Enhancement of Heat Transfer," Proceedings of the Sixth International Heat Transfer Conference, Vol, 6, Toronto, 1978, pp. 89-108.

5. Bergles, A.E., "Bibliography on Augmentation of Convective Heat and Mass Transfer," Part 1, Previews of Heat and Mass Transfer, Vol. 4, No. 2, July, 1978.

6. Bergles, A.E., "Bibliography on Augmentation of Convective Heat and Mass Transfer," Part 2, Previews of Heat and Mass Transfer, Vol. 4, No. 4, July, 1978.

7. Bergles, A.E., Webb, R.L., Junkhan, G.H., and Jensen, M.K., "Bibliography on Augmentation of Convective Heat and Mass Transfer," HTL-19, Iowa State University, Ames, Iowa, May, 1979.

8. Webb, R.L., "The Use of Enhanced Surface Geometries in Condensers," Proceedings of the Workshop on Modern Developments in Marine Condensers, Naval Postgraduate School, Monterey, California, March, 1980, pp. 283-321.

9. Bergles, R.E., and Jensen, M.K., "Enhanced Single-Phase Heat Transfer for Ocean Thermal Energy Conversion Systems, " HTL-13, Iowa State University, Ames, Iowa, April, 1977.

10. Search, H.T., and Marto, P.J., "A Feasibility Study of Heat Transfer Improvements in Marine Steam Condensers," NPS 69-77-001, Naval Postgraduate School, December, 1977.

11. Lynch, V.J., A Comparative Study of a Steam Surface Condenser Computer Model to Field Test Data, M.S. Thesis, Naval Postgraduate School, Monterey, California, December, 1979.

12. Johnson, C.M., Vanderplaats, G.N. and Marto, P.J., "Marine Condenser Design Using Numerical Optimizations," J. of Mechanical Design, Vol. 102, July 1980, pp. 469-475.

13. Krohn, R.L., An Experimental Apparatus to Study Condensation Heat-Transfer of Steam on Horizontal Tubes, MS Thesis, Naval Postgraduate School, Monterey, California, 1982.

14. Rose, J.W. and Yau, K.K., Effects of Fin Spacing and 'Drainage' Strip on the Condensate Heat-Transfer Performance of Horizontal Low Integral-Fin Tubes, Project Report, Department of Mechanical Engineering, Queen Mary College, University of London, 1982.

15. Yau, K.K., Condensation Heat-Transfer Enhancement by Vapor-Side Geometry Modification, Project Report, Queen Mary College, University of London, 1982.

16. Incropera, F. P., and Dewitt, D.P., Fundamentals of Heat-Transfer, Wiley, 1981.

17. Holman, J.P., Heat-Transfer, McGraw-Hill, 1976.

18. Lee, W.C., Rahbar, S., and Rose, J.W., Forced Convection Film Condensation of Refrigerant-113 and Ethanedicl on a Horizontal Tube, Project Report, Queen Mary College, University of London, 1982.

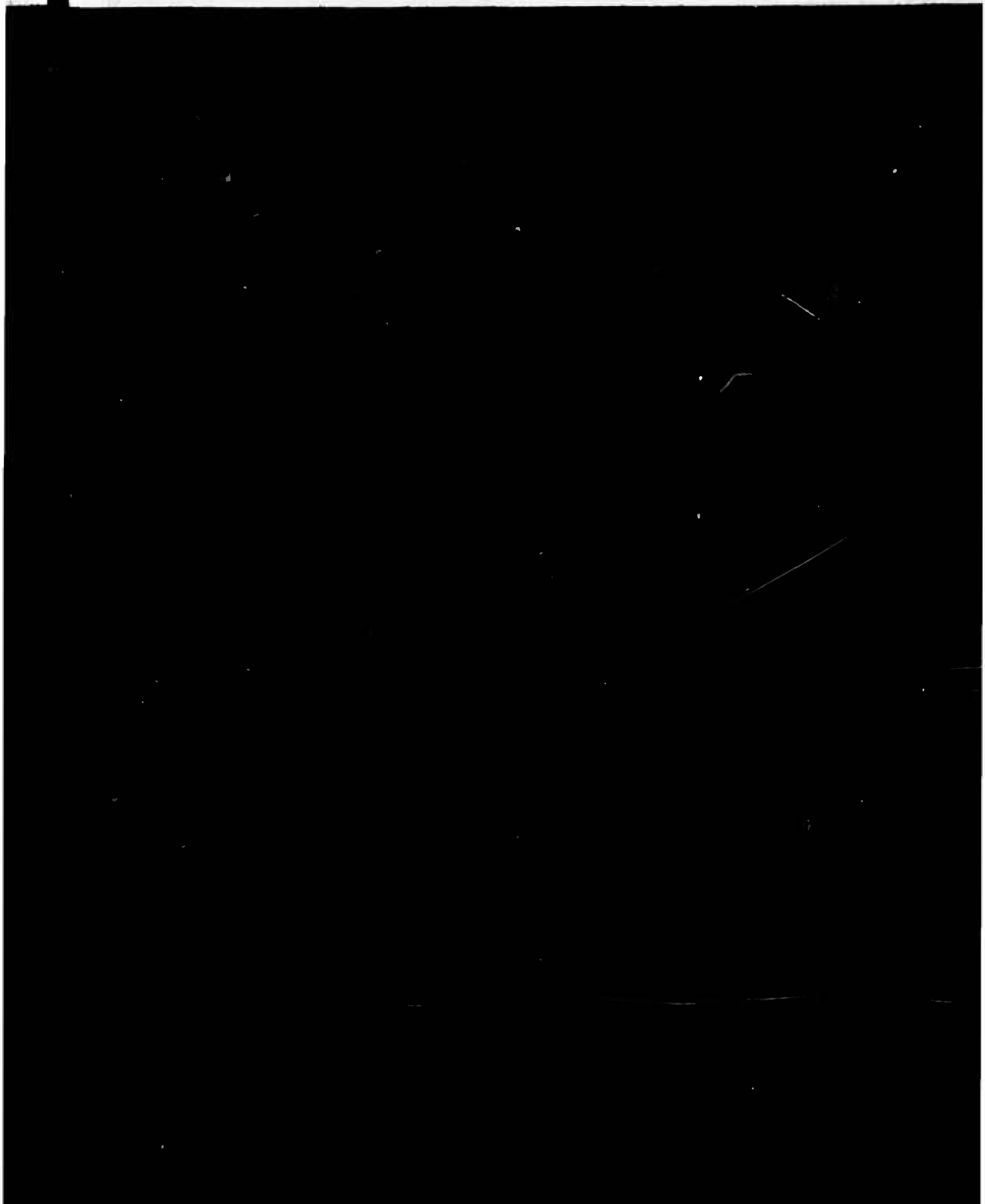
INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3.	Department Chairman, Code 69 Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	1
4.	Professor P. J. Marto, Code 69Mx Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	3
5.	Dr. John W. Rose Department of Mechanical Engineering Queen Mary College University of London London E1 4NS, England	1
6.	Mr. R. W. Kornbau Code 2721 David Taylor Naval Ship Research and Development Center Bethesda, Maryland 20084	2
7.	LCDR Raymond L. Krohn, USN Portsmouth Naval Shipyard Portsmouth, N.H. 03801	1
8.	LT Kenneth A. Graber, USN Naval Education and Training Center Newport, RI 02840	1
9.	Dr. A. S. Wanniarachchi, Code 69 Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	1

DAT
FILM

```
2070  END IF
2080  PRINT " "
2090  PRINT USING "12X,""Position number          :   1    2    3    4    5
   6"""
2100  PRINT USING "12X,""Wall temperature (Deg C) : "",6(DD.DD,1X)";Tw(*)
2110  PRINT USING "12X,""Average wall temperature = "",DD.DD,"" (Deg C)""";Twall
```

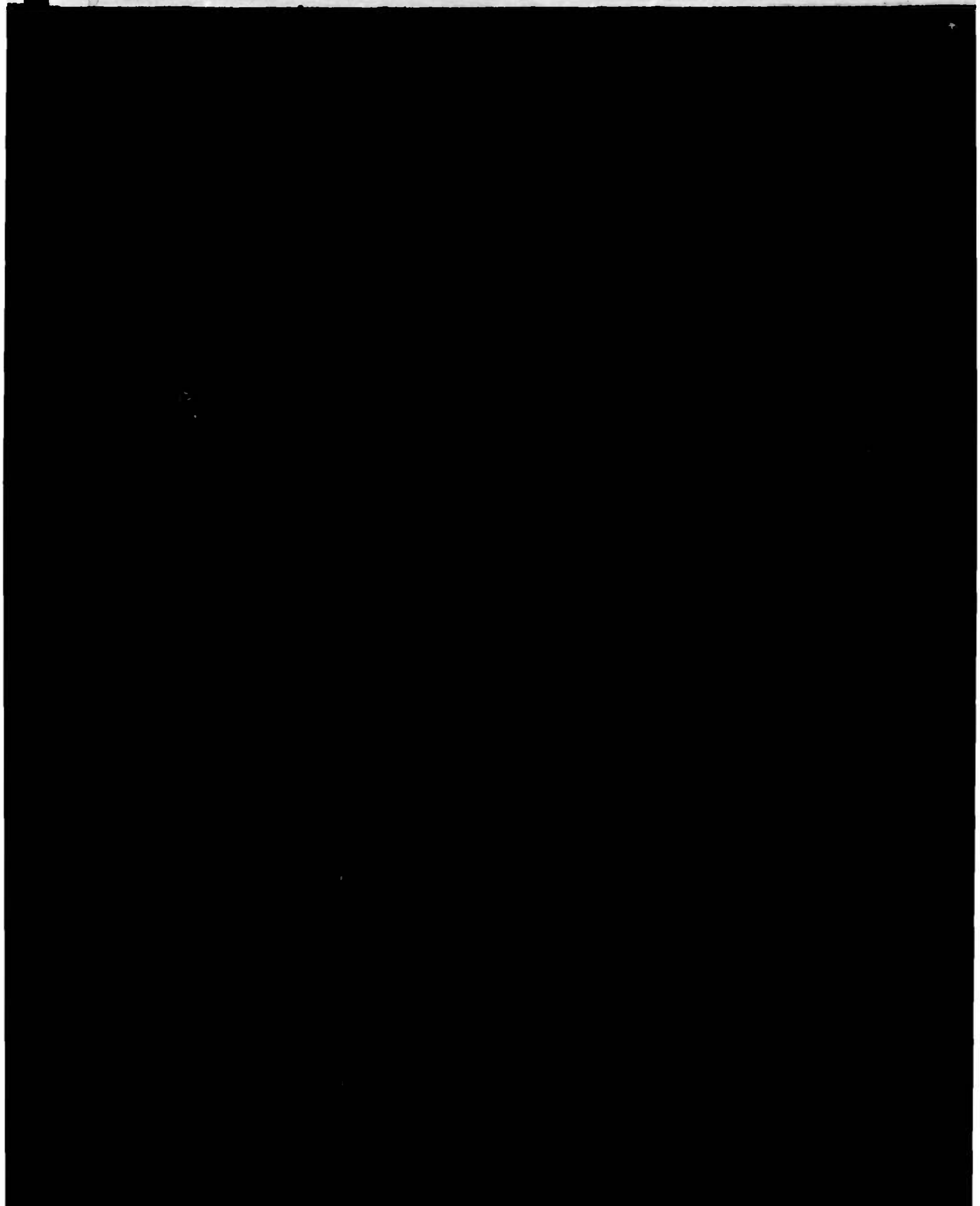
```
2640 RETURN P
2650 FNEND
2660 DEF FNMu(T)
2670 Mu=1.57609473E-3-T*(3.51198576E-5-T*(3.5835816E-7-T*1.365586115E-9))
2680 RETURN Mu
2690 FNEND
2700 DEF FNKw(T)
```



```
1530  PRINT "SR 1.5,2;PU PA 50,-10 CP";-LEN(Xlabel$)/2;"0;LB";Xlabel$;
1540  PRINT "PA -11,50 CP 0,";-LEN(Ylabel$)/2*5/6;"DI 0.1;LB";Ylabel$;""
1550  PRINT "CP 0,0"
1560 Repeat:!
1570  BEEP
```

```
2100  NEXT Xa
2110  END IF
2120  PRINT "PU SP0"
2130  END
```

```
600     [illegible]
610     Dt=Tsteam-Troom
620     PRINT USING "10X,3D.3D,3(DDD.DD,2X)";Power,Tsteam,Troom,Dt
630     K=K+1
640     IF Im=1 THEN
650     BEEP
```



```
Position number           :   1     2     3     4     5     6
Wall temperature (Deg C) : 67.18 64.46 58.95 51.63 63.76 55.68
Average wall temperature = 58.53 (Deg C)
Inlet water temperature  = 31.91 (Deg C)
Outlet water temperature = 33.28 (Deg C)
```